

Issue 64

THE SCIENCE OF EVERYTHING

Aug—Sep 2015

COSMOS

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COVER STORY & FEATURES

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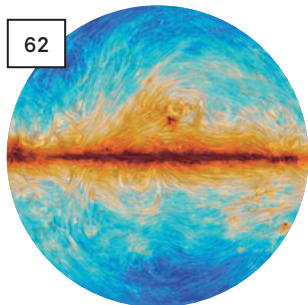


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We now have a scrapyard surrounding the planet. DAN CLERY reports on the dangerous clutter threatening satellites in low-Earth orbit.

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The 30-year-old theory of cosmic inflation is facing a challenge. MICHAEL D. LEMONICK explains.

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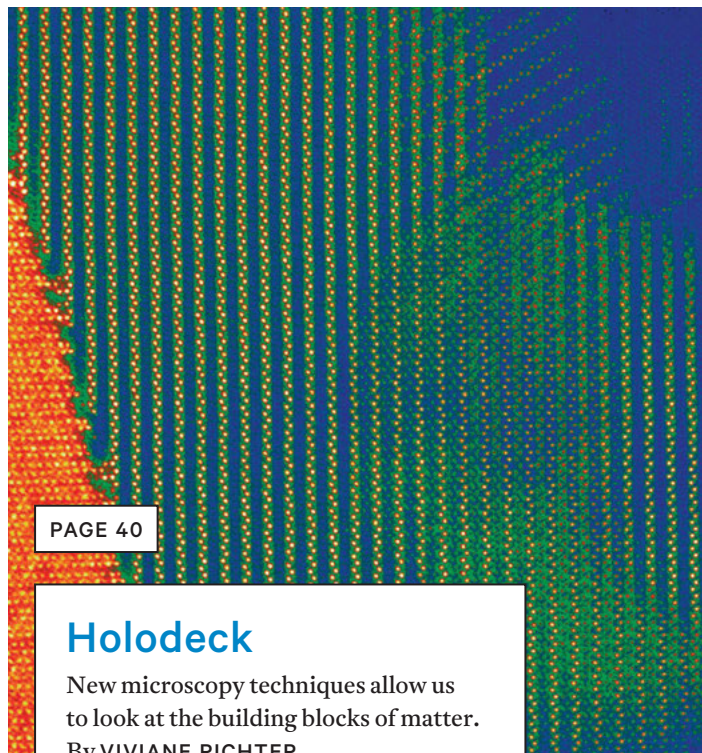
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ON THE RIGHT SIDE OF HISTORY

ELIZABETH FINKEL profiles IVF and stem cell pioneer Alan Trounson about a career that changed the world.

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DISPATCHES, ESSAYS & REVIEWS



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Holodeck

New microscopy techniques allow us to look at the building blocks of matter.
By VIVIANE RICHTER.



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Congratulations to astronomy's brightest new star.

**UWA graduate Dr. Morag Scrimgeour
is the proud recipient of this year's
Charlene Heisler Prize.**

Studying under and alongside an international team of experts at the UWA node of ICRAR (the International Centre for Radio Astronomy Research), Dr. Scrimgeour has established herself as one of the most brilliant scientific minds of her generation.

She has been awarded by the Astronomical Society of Australia in honour of her thesis, "Cosmology with Large-scale Structure and Galaxy Flows." Through mapping distant galaxies, Dr. Scrimgeour's research has provided evidence of the homogeneous distribution of galaxies in the Universe.

Through collaborative research, scientists at UWA are working to change our world and discover new ones.

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CONTRIBUTORS



DANIEL CLERY

Daniel is a science writer and editor based in Woodbridge, UK. A long time news editor with *Science* magazine, he has written for *Physics World*, *New Scientist*, *Popular Science*, the *Bulletin of the Atomic Scientists*, *Huffington Post* and the *Financial Times*. Daniel holds a degree in theoretical physics from York University, and is the author of *A Piece of the Sun: the Quest for Fusion Energy*.



MICHAEL D. LEMONICK

Michael is a writer for Climate Central, an independent organisation that reports on climate change in the US. Before this he covered science and the environment at *Time* magazine for nearly 21 years. He has also written for *Discover*, *Scientific American*, *Wired*, *New Scientist*, *The Washington Post* and *National Geographic*. Michael is the author of six books including *Echo of the Big Bang*.



JEFFREY D. PHILLIPS

An award-winning Melbourne-based illustrator, Jeffrey is known for his brand of quirky pen and ink drawings. Besides editorial work he also art directs, draws storyboards for film and TV and illustrates live at events if required. He restricts himself to two cups of coffee a day and plans his entire schedule around when and where these may be consumed for maximum effect.

EDITORIAL

Editor-in-chief ELIZABETH FINKEL
Online editor JAMES MITCHELL CROW
Deputy editor BELINDA SMITH
Spectrum editor BILL CONDIE
Production editor KATHERINE KIZILOS
Art director ROBYN ADDERLY
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Reporters VIVIANE RICHTER, MEGAN TOOMEY
Fiction editor CAT SPARKS
Editor-at-large WILSON DA SILVA

ADVERTISING

Advertising manager KAREN TAYLOR
+61 414 218 575
advertising@cosmosmagazine.com

MARKETING & COMMUNICATIONS

Digital marketing coordinator TESS WARDLE
Communications advisor ANDREW BRADLEY
+61 403 777 137
andrew@holdfastcommunications.com.au
Media relations BRIAN JOHNSON
+61 2 6582 3311

DISTRIBUTION

GORDON & GOTCH
Australia — 1300 650 666
New Zealand — +61 9 979 3018

SUBSCRIPTION & SALES

Subscriptions manager CHANTELE VIANI
Publisher's assistant JACQUIE SMITH
+61 3 9829 0407
subscribe@cosmosmagazine.com
cosmosmagazine.com/shop

OFFICE CONTACT

Website cosmosmagazine.com
Editorial inquiries info@cosmosmagazine.com
+61 3 9829 0408
PO BOX 254, Toorak Victoria 3142 Australia

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EDITOR'S NOTE



ELIZABETH FINKEL
Editor-in-chief

Flying into a MERS outbreak

ON 8 JUNE I FLEW INTO SEOUL for the World Congress of Science Journalists and an outbreak of Middle East Respiratory Syndrome (MERS). The conference organisers made a virtue of the crisis, welcoming attendees to the biggest science story of 2015 while providing reassurances there was little risk.

Next morning scientists from the frontline of the outbreak briefed the journalists. It appeared that a businessman had brought the disease into Korea after visiting the Middle East. He had been diagnosed on 20 May. Over the ensuing two and a half weeks, Koreans had succumbed at an alarming rate – with 50 infected and two dead. MERS had not been considered particularly infectious. Had it mutated to a more virulent form? The virus had first been identified in Saudi Arabia in 2012, when it jumped from camels – its normal host – to people.

The Koreans were excellent detectives. Their “contact tracing” showed that all the infections had occurred in hospitals – many at one of the two hospitals where the businessman had been examined. The infection was not spreading in the general community. I was reassured that I would not pick it up at shopping malls, the convention centre or the airport. Indeed one infected person caused great alarm by catching a plane to China – but no one was infected.

So why were the hospitals so vulnerable?

For several reasons. The virus resides deep in the lungs and, in contrast to influenza, is not easily spread through coughing or sneezing. But people infected with MERS often have difficulty breathing. In hospital the breathing tube placed into their lungs liberates the virus particles. The air-conditioning systems spread these aerosols far and wide, especially in crowded emergency rooms.

Hospitals are also primarily responsible for spreading the virus in the Middle East. This suggested MERS had not mutated to a more virulent form; reading the DNA sequence has since confirmed this. Nevertheless, the South Koreans were taking no chances. More than 100 schools were closed, the subways were sanitised and face masks were rife.

A month later, 35 Koreans had died from MERS and 186 were infected. Most of those who died had a pre-existing medical condition that put them in hospital in the first place – or were elderly hospital visitors. But some fit younger people had also died including health care workers. The average age of those who died was 55.

The spread of the virus seems to have slowed: hospitals are taking care to isolate sick patients; some have even shut down.

In the last month, two new MERS cases have been reported in the Philippines and Thailand from businessmen who recently travelled to the Middle East. Close contact with an infected camel or person – both may be asymptomatic – could be responsible. Or they may have merely tried a local dish containing infected camel milk or meat. So far, the answers are not forthcoming. Contact tracing is much harder in the Middle East. Businessmen and women beware. ☹

ISSUE 64



COVER

Thanks to decades of sending satellites and rockets into space, we're now surrounded by layers of potentially devastating junk whizzing around Earth's orbits.

CREDIT: ESA / SPACEJUNK3D, LLC

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FEEDBACK



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THE CASE FOR RETAINING PLUTO IN THE PLANETARY FAMILY

I wish to respond to the one problematic statement in the very informative article, "Knocking on Pluto's Door" (*Cosmos* 63, page 80), namely the acceptance of the controversial demotion of Pluto at face value.

Richard Lovett states: "Pluto's demotion from planethood kicked it from the fringe of our more familiar Solar System. It is now part of the Kuiper Belt, where astronomers have spotted enormous numbers of equally mysterious objects floating on the Solar System's dark edge." What he unfortunately neglects to mention is that Pluto's demotion remains a highly controversial matter and a subject of ongoing debate, rather than a done deal. Only four of the IAU even voted on this, and most are not planetary scientists but other types of astronomers. Their decision was immediately opposed in a formal petition by hundreds of professional planetary scientists led by Dr. Stern.

— LAUREL KORNFELD,
Highland Park, NJ, USA

or Uranus. What's important isn't what Pluto is called, but the fact that we are going there. That's exciting. The rest is nomenclature.

THE UNBEATABLE POKER PROGRAM

I challenged the unbeatable poker machine Cepheus (*Cosmos* 62, page 26) to 100 hands of poker and came out with about \$320 on top! So not sure if you would like to tell the inventors of this game it's far from flawless. Or I am just the best poker player in the world? Which I highly doubt.

Keep up the good work with your magazine.

— ADAM MOKRYCKYJ
via email

A SUGGESTION FOR A MOBILE PHONE WITH DEFIBRILLATOR

Drones (*Cosmos* 63, page 34) are expensive, weather-dependable, have limited range and are easy-crash devices. Why not develop a defibrillator as an attachment to a mobile phone, or even a phone with a defibrillator? Used by a person with a heart problem, always charged, immediately accessible, with instructions for how to use it on the screen. The phone could detect lack of heart beats (with a special sensor or bracelet), raise the alarm and call an ambulance.

The device would be good for people far from hospital such as farmers, hunters,

fishermen and bush trackers. Even for people taking care of elderly parents. I can see big demand for it.

— JACK TALIKOWSKI
Heathridge, WA, Australia

REPLY FROM EDITOR:

We agree that mobile phones can be useful diagnostic aids. Our reporter Viviane Richter has prepared a feature on new health apps in this issue (see Gadgets and Gizmos, page 114). Who knows, in future we may also see an app designed for cardiac patients at risk.

PLEASE KEEP THE LOOK OF THE REDESIGNED COSMOS

I love the new look *Cosmos* Magazine and was disappointed to read in "Feedback" (*Cosmos* 62, page 10) that you intend to change the cover because a few subscribers have complained about it.

I think the hard cover makes a statement that this is a quality magazine, suitable for keeping on the bookshelf for future reference, and should be retained.

— JOHANNES SMIT
via email

REPLY FROM RICHARD LOVETT:

Ms. Kornfeld is correct that some people want to reinstate Pluto as a planet. But at the moment, it isn't one. Furthermore, it really does have more in common with Kuiper Belt objects such as Eris, Sedna, Haumea and Makemake than it does with planetary neighbours such as Neptune

REPLY FROM EDITOR:

We love the new look *Cosmos* too, and so have only reduced the paper stock of the cover slightly.

LEADERS

ISSUE 64

KEEPING SPACE CLEAR OF JUNK

Imagine a world without satellites. Start by saying goodbye to Google maps and watching your soccer match in real time. Our interconnected world would suddenly be unplugged. Weather forecasting, air, land and sea travel, computer systems and military operations would all be severely disrupted.

And with no satellite data, how are we to monitor the state of the planet's forests, ice sheets or crop yields?

That's the future we face unless we can figure out how to do a massive clean-up job in space. Over the last few decades, low-Earth orbits have become a junkyard. But this is deadly junk. Racing around the planet at 10 kilometres per second, everything from defunct satellites to flecks of paint become dangerous missiles that can cripple satellites or puncture

an astronaut's suit on a spacewalk.

The catastrophic scenario — dramatised in the movie *Gravity* — is a collision that generates a debris shower. In a cascade of destruction, each piece of debris collides with a larger target until space becomes a minefield. The proof of concept happened in January 2007. China tested a space weapon against one of its own ageing weather satellites, Fengyun 1C. The impact created around 3,000 pieces of sizeable debris. It happened again in 2009 with the collision of an Iridium Communications satellite with a dead Russian military communications satellite, showering space with 2,000 grapefruit-sized fragments.

This debris cascade is named the "Kessler syndrome" after NASA scientist David Kessler who warned of this scenario in 1978. After being sidelined for decades, his warning is now being heeded. Defunct

satellites and rockets are now designed to re-enter the atmosphere where they will burn up.

But as Dan Clery reports in this issue, that is only a partial solution. Models predict space debris will grow by 30% over the next 200 years, mostly fed by collisions that will happen every five to nine years. No one knows how to clean up the mess. Lasers are not sufficiently advanced and once they become so, they will also be lethal space weapons. Encouragingly, the Europeans are experimenting with nets and harpoons for a possible demonstrator mission in 2021. The Swiss will test a retrieval system with a net in 2018.

Human nature is another obstacle. Aspiring astronauts don't dream of becoming space junk disposal workers. That's a pity, because somebody has to do it. ☹

TINKERING WITH HUMAN LIFE

Alan Trounson has spent most of his life battling at the frontline of controversial medical breakthroughs. From the 1970s to the 1990s he pioneered IVF treatments. From the late 1990s to 2000s, he harnessed the potential of human embryonic stem cells. From 2007 until 2014, he led the world's biggest, boldest push to drive stem cells into new medical treatments as president of the California Institute of Regenerative Medicine (CIRM).

For all this, he has recently been honoured in Stockholm with a public service award from the International Society of Stem Cell Research. His work has also attracted an extraordinary degree of controversy because it forced society to confront profound questions: when does human life begin and are we prepared to destroy human embryos for medical purposes? Obtaining human embryonic stem cells, for instance, requires the destruction of a five-day-old embryo.

But these are usually frozen leftovers from IVF clinics that would otherwise be thrown away.

In the case of IVF, Trounson has emerged triumphant. Five million babies have now been born this way; in the space of a generation the technique has mellowed from a red-hot source of controversy to a commonplace. At the same time, many of the feminist predictions about IVF's disruptive social impact have come to pass. Women were once prisoners of their biological clock. Now a woman can delay child-bearing by freezing her eggs. Surrogacy has become a commercial practice. Children have been born without knowing the identity of their biological parents. Same sex couples can use IVF to make children of their own.

Will Trounson's push at the frontiers of stem cell research be equally transformative? CIRM was given \$3 billion and 10 years to deliver new cures. Trounson has been widely praised for his cohesive leadership and bold vision.

His legacy is 20 clinical trials



testing the use of stem cells to deliver new treatments for an extraordinary breadth of diseases: type 1 diabetes, blindness, eradicating HIV infection, cancer and spinal cord injury to name a few.

There's no doubt the science and the scientists at CIRM are first class. But will this titanic injection of funds be enough to break the stranglehold of some of mankind's most intractable diseases?

The world is waiting to see.

One thing's for sure, the farm-boy from Jerilderie has left an extraordinary legacy. And he's not done yet. ☹

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WEB

WHAT ON CERES ARE THOSE BRIGHT SPOTS?

As NASA inches closer to an answer, astrophysicist Alan Duffy weighs the possibilities - ice, a volcano, or some other, unforeseen option.

→ bit.ly/ceres_brightspots

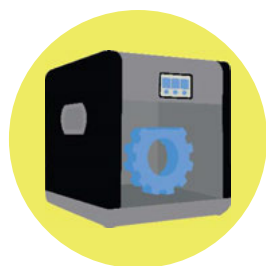


BLOG

ANTI-STATIN DOCUMENTARY TURNS THOUSANDS AWAY FROM CHOLESTEROL DRUG

A study in Australia found that tens of thousands of people stopped taking cholesterol-lowering statins in the wake of a television documentary that described the drugs as toxic.

→ bit.ly/antistatin



WEB

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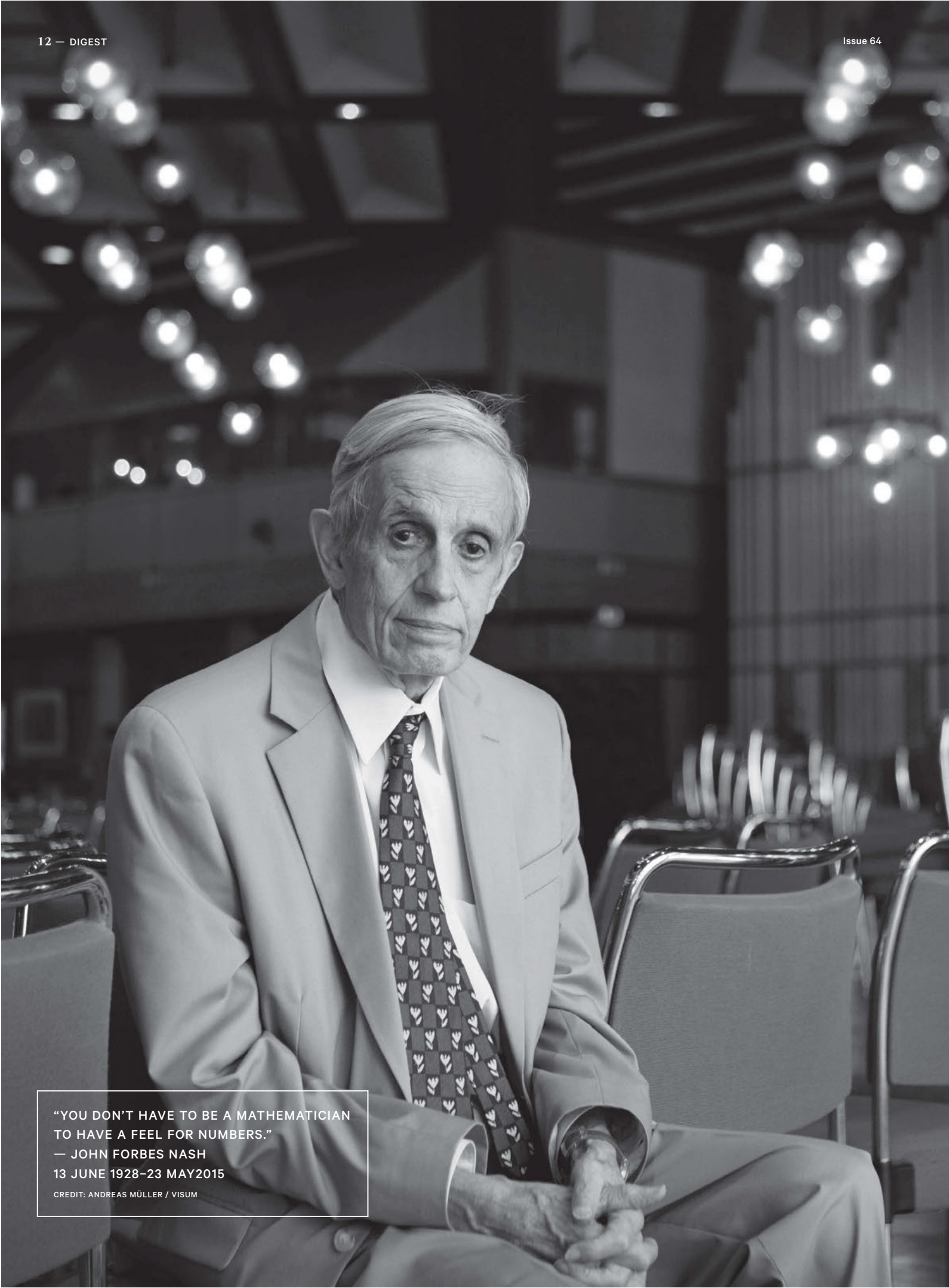
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THE AGE





"YOU DON'T HAVE TO BE A MATHEMATICIAN
TO HAVE A FEEL FOR NUMBERS."

— JOHN FORBES NASH

13 JUNE 1928–23 MAY 2015

CREDIT: ANDREAS MÜLLER / VISUM

A CLOSER LOOK AT THE BIG STORIES

DIGEST



TECHNOLOGY

The most accurate clock ever made

A strontium clock now has the accuracy to detect changes in gravity. CATHAL O'CONNELL reports.

Scientists have succeeded in making a clock so precise it could tick for 15 billion years – longer than the age of the Universe – without gaining or losing a second. →

At the heart of the clock mechanism, above, lies a blue cloud of strontium atoms. The tick rate – 430 trillion times a second – is set by the quantum leaps of their electrons.

CREDIT: THE YE GROUP / BRAD BAXLEY / JILA

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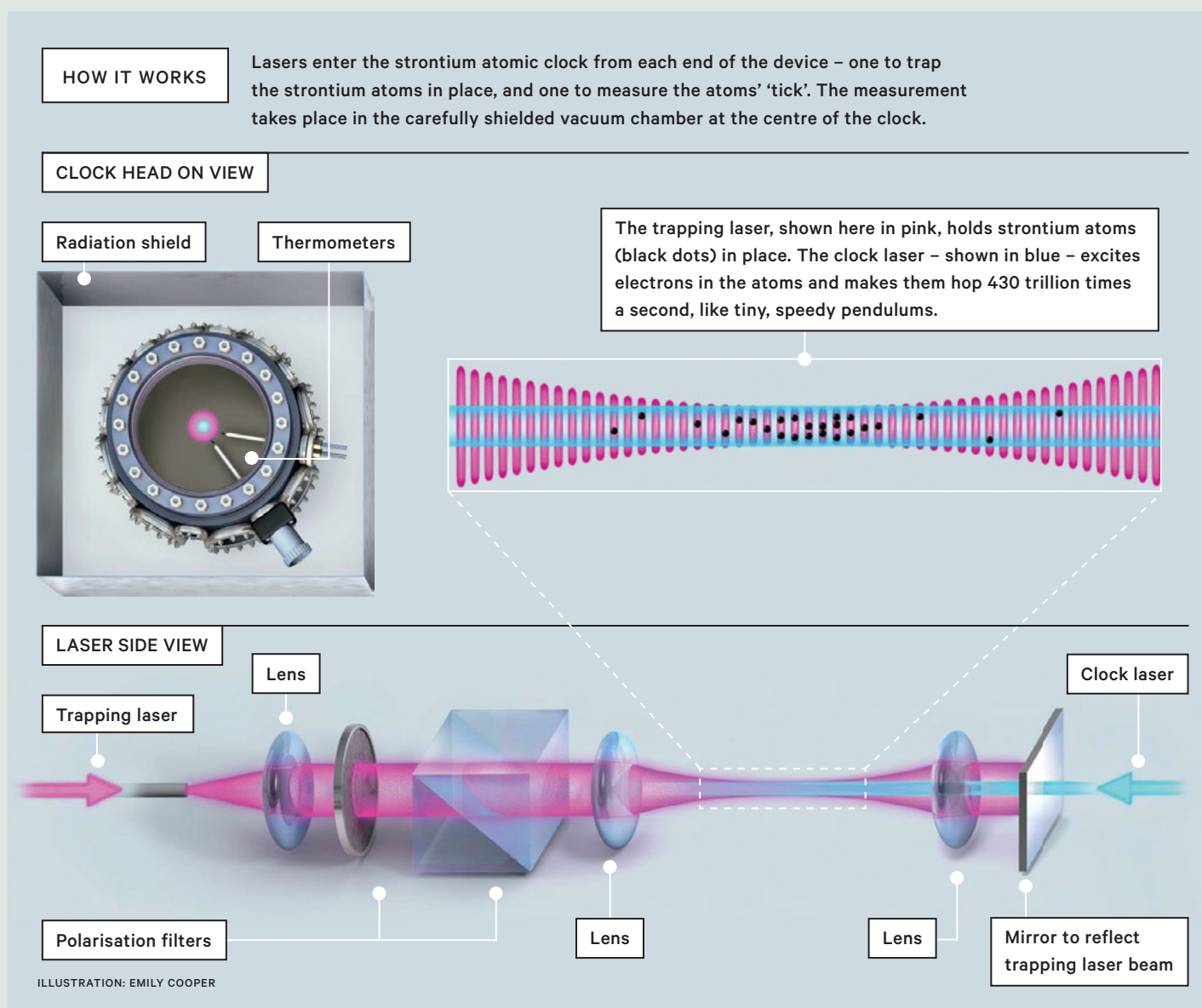
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→ The new research, described in *Nature Communications*, sets a world record for accurate timekeeping and is a three-fold improvement over the previous record, set by the same clock in Boulder, Colorado, last year.

On a practical level, the optical lattice atomic clock Jun Ye and his colleagues at the US National Institute of Standards and Technology are developing could replace the caesium atomic clocks used in GPS systems and internet communications.

But if Ye can continue to improve the clock's performance its accomplishments will go far beyond keeping time. It will allow us to measure what Einstein theorised: gravity's effects on the passage

of time. And that will unleash possibilities both practical and profound – from prospecting for minerals to probing the nature of dark matter.

"We feel we are in the middle of a revolution," says Ye. "For the next 10 years I am fairly bullish to say we can make another factor of five or 10 improvement."

All clocks need a ticking mechanism to keep the beat; and the faster they tick the better. "When you divide time in finer intervals, you get a better resolution of timekeeping," says Jérôme Lodewyck, a researcher in atomic clocks at SYRTE (SYstèmes de Référence Temps-Espace) at the Paris Observatory.

Early mechanical pendulum clocks

were accurate to within about 15 seconds per day. In the 1920s they became accurate to within one second per day when tapped into the ticking of quartz crystals – they vibrate at thousands of times per second when zapped by an electric current.

Since the 1950s, the world's best clocks have been based on atoms such as caesium and strontium. As the electrons leap between energy levels they shed excess energy, flashing a photon of a specific (quantised) wavelength as they go. "Now, timekeeping belongs to quantum physicists," says Lodewyck.

In standard caesium atomic clocks the leaping rate is nine billion times a second, meaning they won't gain or lose

a second in a few hundred million years. But strontium ticks at 430 *trillion* times a second – and that’s what Ye’s clock uses.

In the clock a cloud of strontium atoms float in a vacuum chamber criss-crossed by lasers that hold the atoms in position, like flies caught in a spider’s web. A second laser beam excites the atoms with visible light. The clock measures the light flashes from the leaping electrons to calibrate its ticking.

Because they are activated by visible light strontium clocks are known as optical clocks, as distinct from the microwave frequency photons used by caesium clocks.

“CLOCKS LIKE THIS CAN BE EXPECTED TO MEASURE THE DIFFERENT GRAVITATIONAL POTENTIAL OF A GOLD MINE, OR OIL ... ”

In the recent work Ye went on to beat his own accuracy record by fine-tuning the strontium cloud chamber.

The wavelength of the flashes released by the leaping electrons can shift slightly depending on the atom’s environment – for example, whether it is being jostled by radio waves.

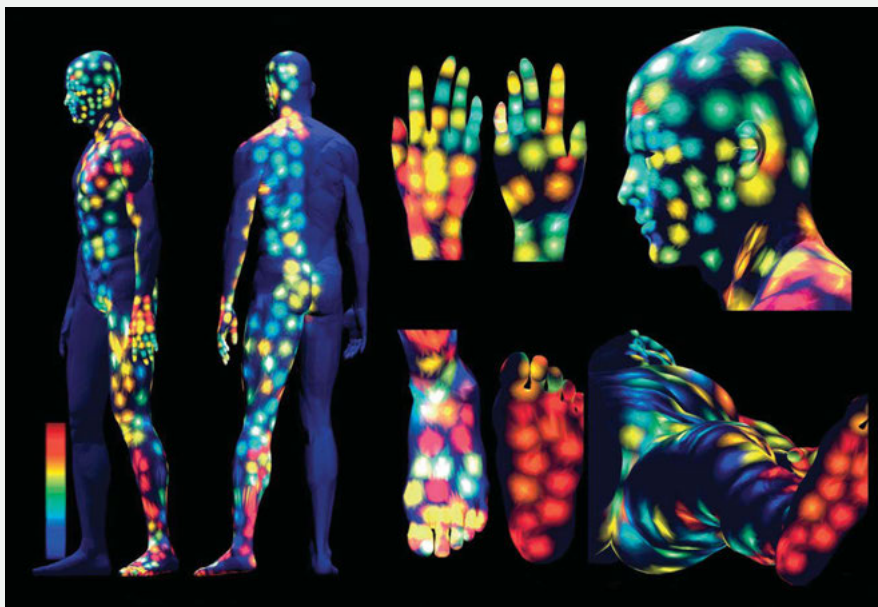
To protect the atoms, Ye’s team built a radiation shield for the atom chamber. They painstakingly measured any wavelength shift to the atomic levels caused by heat and calculated how to compensate for it by taking the temperature inside the chamber. They also improved the way the laser mesh trapped the atoms to ensure it does not disturb the atomic ticking. These tweaks broke the 2014 accuracy records by a factor of three! The improvements will eventually lead to applications that seem straight out of science fiction.

Einstein’s theory of relativity holds that time flows at different rates depending on gravity and the speed of travel – GPS satellites correct for this to stay accurate. In 2010 Ye showed this effect when he placed one of his atomic clocks on a shelf above a second one – the lower clock ran slower because it was one metre closer to the Earth.

The group aims to make optical clocks so accurate they can detect changes in

CAPTURED

MOLECULE MAPS



The surface of our skin is a chemical wonderland. That’s what Pieter Dorrestein at the University of California, San Diego and colleagues found when they took multiple skin swabs from two volunteers to chart their chemical and microbial diversity. The chemical diversity of their skin is represented here on these colourful dot maps – ranging from low (blue) to high (red).

So where do all these chemicals come from? Skin cells and microbes make them and many come from the products we smear on ourselves. But chemical reactions that take place on the skin also create new compounds. More than 80% of the molecules on the volunteers’ skin did not match known compounds, the research showed. Of those molecules that could be identified, ingredients from the volunteers’ hygiene and cosmetic products dominated many areas – even though the volunteers had not applied these products, or even showered, for three days before the study. The researchers will use these maps to see how chemicals affect the make-up of microbes on the skin. The study was published in the *Proceedings of the National Academy of Sciences*.

— JAMES MITCHELL CROW

CREDIT: THEODORE ALEXANDROV

gravity caused by materials of different density in the ground beneath them.

“Clocks like this can be expected to measure the different gravitational potential of a gold mine, or oil or a large body of water,” says Ye.

And then there’s the possibility of detecting gravitational waves – ripples in time predicted by Einstein but never directly detected – as they wash over the

clock. Dark matter might be detected in a similar way.

Ye’s team is now seeking to make the lasers more stable so they are always tuned to the frequency that excites strontium atoms. “As you’re marching towards the next decimal point sometimes you can predict the effects, sometimes you don’t,” says Ye. “There are always surprises, that’s part of the fun of this game.” ©



LIFE SCIENCES

One blood type for all looks within reach

An enzyme that renders foreign red blood cells invisible to the immune system could hold the key to making blood type irrelevant in transfusions. VIVIANE RICHTER reports.

There's a one in three chance you'll need a blood transfusion in your life. The wrong blood type could trigger a fatal immune response. Universal O-type blood doesn't trigger that response but is in short supply. Now, researchers in Canada are closing in on a way to make all blood universal.

The technique uses enzymes to snip away molecular flags on red blood cells that rile the immune system. Biochemist Stephen Withers and his team at the University of British Columbia published their findings in the *Journal of the American Chemical Society*.

"Having a process to make any blood type universal would be remarkable," says David Irving, head of research and development at the Australian Red Cross Blood Service.

The surface of red blood cells bristle with sugars and protein chains.

In the early 1900s, Austrian physicist Karl Landsteiner discovered blood comes in four types – A, B, AB and O. Each corresponds to particular sugar chain antigens on a red blood cell's surface. These antigens are responsible for triggering the immune response. Inject an A-type person with B-type blood, for example, and antibodies in their bloodstream would recognise the transfused cells as foreign, kick-starting an immune cascade that causes blood to clot.

The exception is O-type blood. These cells carry a shortened version of the A and B antigens that does not alert the immune system, so can be given to almost anyone. O-type blood is most in demand and generally in short supply. A universal blood would alleviate supply problems.

Since the 1980s researchers have tried to develop enzymes that remove antigens from the cells, but have made little headway. Part of the problem is that A and B-type antigens come in several different sub-types, some of which can be altered more easily than others.

To solve the problem Withers turned to an unusual source – an enzyme from the bacterium responsible for pneumococcal disease, *Streptococcus pneumoniae*. The enzyme, called EABase, naturally chops up sugar chains while the bacteria digest food. In the lab it managed to chop the B-antigens off red blood cells, but only one of the four A-antigen chain types.

So Withers increased the enzyme's activity using test tube 'evolution'. The

team made random mutations to the enzyme's antigen-snipping machinery, then tested it. After each round they would identify the best enzyme then mutate it once again. After five rounds, and having tested more than 3,000 mutants, they came across an enzyme that was 170 times more efficient at sugar snipping than the one they started with. The star enzyme, Sp3GH98, could also chop the type-2 antigen which makes up 80% of the blood group A population.

"It's a remarkable feat," says Henrik Clausen, an enzymologist at the University of Copenhagen.

Withers anticipates that once the enzyme is optimised only a milligram – as much as a couple of sugar grains – per bag of blood would be needed to convert all red blood cells to the ABO-antigen-free form.

But first it needs to be tested. After snipping off the sugar the enzyme leaves a stump that's similar – but not identical – to that found in the universal O-type blood. At this stage it's not clear whether the body will develop an immune response to this new "universal" blood type.

Withers says he does not expect an immune response, but Clausen, a veteran of similar research, is not so sure. He believes that the exposed sugar stumps could still potentially trigger an adverse reaction and that the blood may require further processing. Nevertheless, other enzymes should be able to cap the chopped stump to look the same as O-type blood, he says. "Anything is possible." ☺

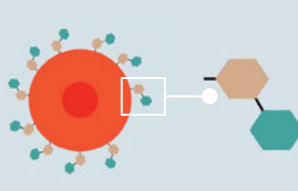
BLOOD TYPES

O-type blood is the most versatile because it is the least likely to trigger an immune response. The enzyme EABase trims antigens on different blood types, leaving only a short stump.

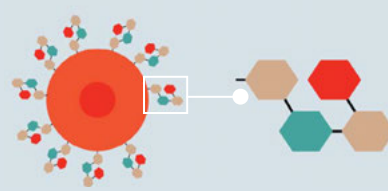
A-type



Trimmed



O-type



KEY (SUGARS)

● Galactose

● N-Acetylglucosamine

● Fucose



PHYSICS

Breakthrough for quantum computers

Quantum computing in silicon has moved a step closer to becoming a reality. CATHAL O'CONNELL explains.

"A quantum computer is to a computer what a jet plane is to a bicycle," says physicist Andrea Morello at the University of New South Wales. And, as was the case with jet planes, building a quantum computer requires some daunting innovations. Morello and his team report their latest breakthrough in *Science Advances*, showing they can use an electrical field to control quantum bits.

QUANTUM COMPUTERS CAN EASILY DIGEST PROBLEMS OF PROBABILITY AND CHANCE.

Morello's team is trying to build a quantum computer from silicon, which already forms the basis of the computer industry. Conventional computers use a binary code of 1s and 0s. They are unparalleled for crunching through massive plodding calculations, but can choke on more complex tasks such as trying to predict the weather. Quantum computers, on the other hand, can easily digest problems of probability and chance. Their code isn't only 1 and 0; it can be 1 or 0, or a "superposition" of both. That characteristic comes from the quantum nature of the quantum bit or qubit. Morello's team has fashioned their qubit as a single phosphorus atom entombed in a silicon crystal. By tuning a magnetic field, they can flip the atom's quantum "spin" to be up, down, or the superposition of both. Theoretically, this should enable a quantum computer to weigh multiple solutions to a complex problem at once.

Over the last five years, in a series

of *Nature* papers, the world-leading researchers showed they can write, read and store the spin of a single quantum bit using a magnetic field. Last year they showed they could do it with better than 99.99% accuracy. But to carry out complex calculations, a quantum computer needs thousands or millions of quantum bits that can be individually controlled. And for that, the high frequency oscillating magnetic field generators Morello has been using are a problem. For starters they are around \$100,000 per bit. For a large array, the costs would be astronomical. And there's a practical problem: magnetic fields spread. So in an array it would be impossible to control one quantum bit without affecting all its neighbours.

Arne Laucht in Morello's lab came up with a solution. Instead of controlling each qubit using a dedicated magnetic field, he found he could use a simple electrical pulse.

The electric pulse controlling the qubit can be compared to a tuning knob on a radio. Morello's plan is to 'broadcast' a single magnetic field across a whole computer of qubits – like a radio station broadcasting across a whole city. Only the radio sets tuned to the correct frequency pick up the broadcast. Similarly, only qubits receiving the electric pulse will be tuned in to the oscillating magnetic field around them.

By timing their electrical pulses, the team could tune the qubit in and out of the oscillating magnetic field and so flip the phosphorus atom's spin into any position they wanted – up, down or an intermediate superposition – without affecting its neighbours.

The idea of combining electric and magnetic fields this way to control individual quantum bits has been around since 1998. Bruce Kane, an American quantum physicist who was then working at UNSW, proposed it in a paper in *Nature*.

Morello is confident all the elements will be in place to build a small-scale test system within 10 years. And as for a large-scale quantum computer? Here, Morello is more coy: "To quote Niels Bohr, 'It's hard to make predictions, especially about the future'" 🌀

IN BRIEF

ATOM SMASHER IS BACK



CREDIT: MAXIMILIEN BRICE / CERN

THE WORLD'S LARGEST atom smasher, the Large Hadron Collider (LHC), is back at work after a two-year revamp.

The 27-kilometre ring under France and Switzerland speeds 100 billion to 1 trillion protons to near light-speed before crashing them into one another, spraying out subatomic particles that exist for fractions of a second. What remains helps scientists understand the fundamental building blocks of nature, such as the Higgs boson.

After \$160 million worth of maintenance and upgrade work the LHC now has almost double the collision energy.

The search this time will focus on detecting enigmatic dark matter and will look for signs of extra dimensions. It will also investigate the theoretical concept of supersymmetry. Physicists hope to prove there is a partner particle for each particle already identified in the Standard Model of particle physics.

— COSMOS EDITORS



SPACE

Comets paint Mercury black

A new theory about Mercury's dark complexion will soon be tested.

JAMES MITCHELL CROW explains.

NASA's Messenger probe to Mercury met a violent end on 30 April this year. Its fuel tanks empty, the probe smashed into the surface of the planet it had been studying since March 2011. Before it crashed, scientists hope Messenger might have solved one of the biggest enigmas about the planet closest to the Sun: its colour.

Though similar in size and composition to our ghostly white Moon, Mercury has a dark complexion and astronomers have long wondered why.

Megan Bruck Syal from Lawrence Livermore National Laboratory in California and her colleagues offered an explanation in *Nature Geoscience* in March: passing comets are showering Mercury with a sooty layer of carbon. Their theory was supported by a laboratory simulation. The hope is that before Messenger's death crash it measured the carbon in Mercury's soil. That data – still to be released – might solve the riddle of the dark planet.

Until recently deposits of iron, not carbon, were considered responsible for Mercury's colour. The planet's feeble gravity can't hold an atmosphere so even meteorites less than 2 millimetres in size – so small they would be incinerated in Earth's atmosphere – frequently smash into Mercury's surface. According to one theory, the source of this iron was pulverised micrometeorites that, in contrast to ordinary iron deposits, form nanoparticles that reflect almost no light.

That theory bit the dust in 2011 when Messenger's instruments detected little nano-iron in Mercury's soil. "It became really clear ... that there was some mystery darkening agent," Bruck Syal says.

Bruck Syal and her colleagues then realised that Mercury is also bombarded by large comets which can be rich in carbon. Their models showed most of them would strike the planet so fast they'd ricochet off again. But their dusty trails, which can be up to 25% carbon, would shower the planet. The team calculated that over billions of years, accumulated comet soot could have left Mercury with a surface that is up to 6% carbon. Since Mercury's orbit is so close to the sun, its neighbourhood is packed with melting, disintegrating comets. It would likely receive 50 times more carbon dust than the Moon, explaining their different hues.

To find out what form would this carbon might take, Bruck Syal ran impact tests at NASA's Ames Vertical Gun Range. She mixed a form of carbon – sugar – with a fine grey basalt powder

that approximated Mercury's soil, then fired projectiles into the mixture at five kilometres per second to mimic micrometeorite bombardment. The heat created by the impacts vaporised the sugar to graphite that darkened Mercury's soil as it resettled on the surface. When they repeated the experiment without sugar, the soil remained lightly coloured – confirming that carbon, mixed in with Mercury's soil through micrometeorite bombardment, could be what darkened the planet

"This seems like a really nice, elegant solution to the problem of Mercury's dark colour," says Jonti Horner, a planetary astronomer at the University of Southern Queensland. "They did the mathematical modelling first and said, 'hang on, this can work, let's see if you can actually get the darkening in the lab'".

SINCE MERCURY'S ORBIT IS SO CLOSE TO THE SUN, ITS NEIGHBOURHOOD IS PACKED WITH MELTING, DISINTEGRATING COMETS.

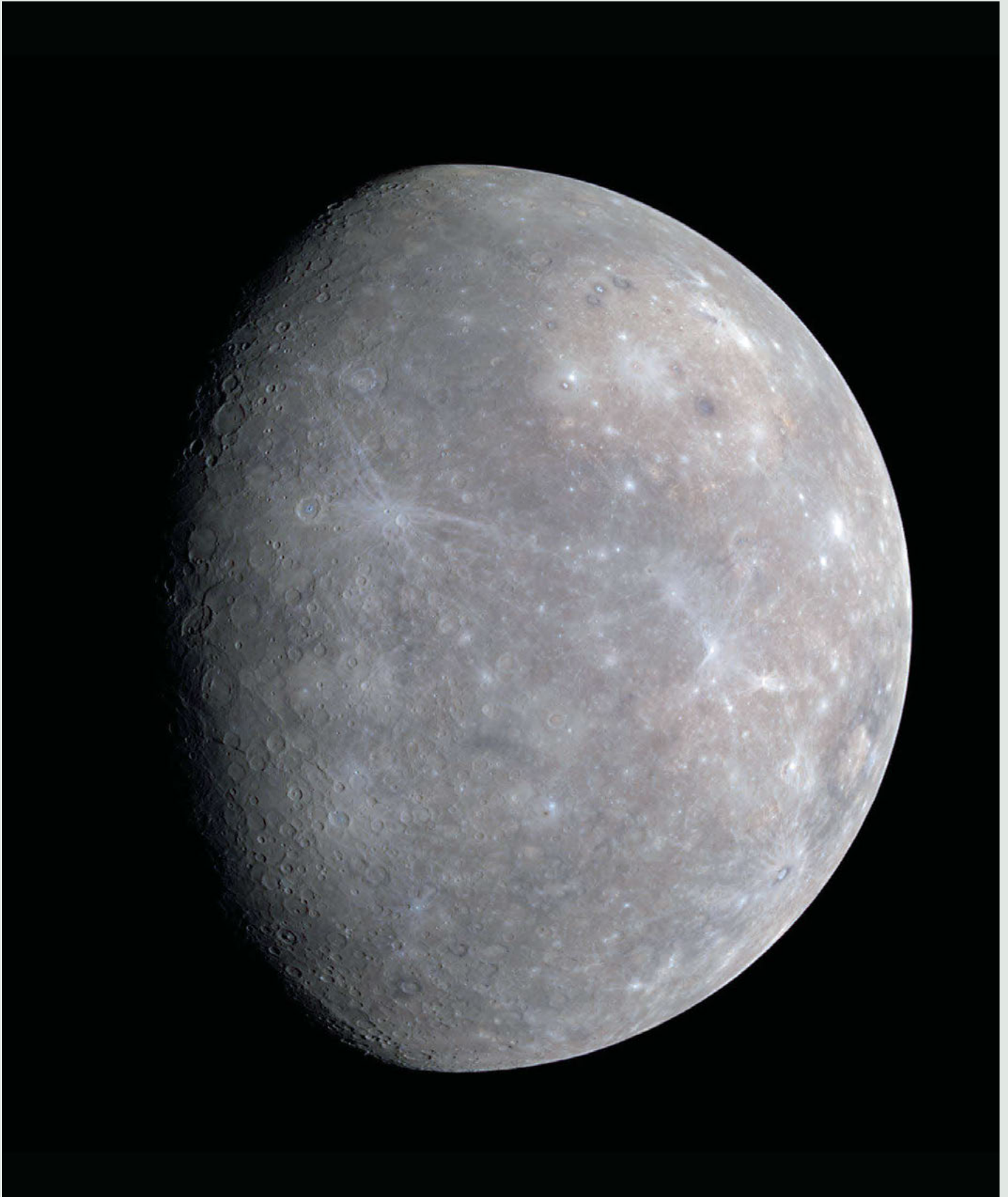
And the icing on the cake would be if Messenger could posthumously confirm that Mercury's surface is carbon-rich. Bruck Syal is awaiting what she expects will be a series of papers from Messenger scientists. The probe should have been able to measure the signatures of elements in Mercury's soils by analysing the echoes of cosmic rays that pelt the planet's surface. When these high-energy rays strike an atom in Mercury's soil, they knock loose a neutron that carries the energy signature of the atom that emitted it. Even in its high orbit, Messenger's instruments could detect the energy signature of iron, but carbon's emissions are harder to pick out from afar.

Hence the hope that in its last pass over the surface, Messenger picked up a carbon signal.

But even if Messenger ends up failing to detect carbon, Bruck Syal won't lose hope. A joint European-Japanese mission, due to launch in 2017 and arrive in 2024, will carry a host of instruments to analyse Mercury's surface composition. "That mission could answer the question." ©



An artist's impression of the Messenger probe flying over Mercury's surface. CREDIT: NASA



Could Mercury's dark complexion be soot from comet trails? Messenger's final journey over the planet may tell us.

CREDIT: NASA / JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY / CARNEGIE INSTITUTION OF WASHINGTON



SPACE

Microwave ovens wreak havoc with radio telescopes

Appliances make life easier but not for radio astronomers. BELINDA SMITH explains.

Short, mysterious bursts of radiation picked up by the Parkes radio telescope in New South Wales have baffled astronomers for years. But it turns out they are neither a new kind of star nor a message from ET.

Emily Petroff from Melbourne's Swinburne University discovered they are wayward blips of radiation from microwave ovens at the observatory. It turns out impatient users were opening the oven door before the countdown finished. When the telescope's rotating dish pointed in the direction of the oven,

it detected the radiation burst. Petroff and colleagues published their findings in the online archive *arXiv*.

Radio waves represent the longest wavelengths of the electromagnetic light spectrum, ranging in size from 100 kilometres all the way to centimetre-long microwaves. They can be generated by excited organic molecules or exploding stars. Many have travelled here from billions of light-years away and their wavelengths have been stretched to the longest part of the spectrum. By analysing them, radio astronomers are piecing together the ancient history of our Universe. In 1960 for instance, radio astronomers Arno Penzias and Robert Wilson pointed their antenna into the New Jersey sky and detected microwave radiation coming from every direction of the Universe. It turned out to be the 14-billion-year-old echoes of the Big Bang.

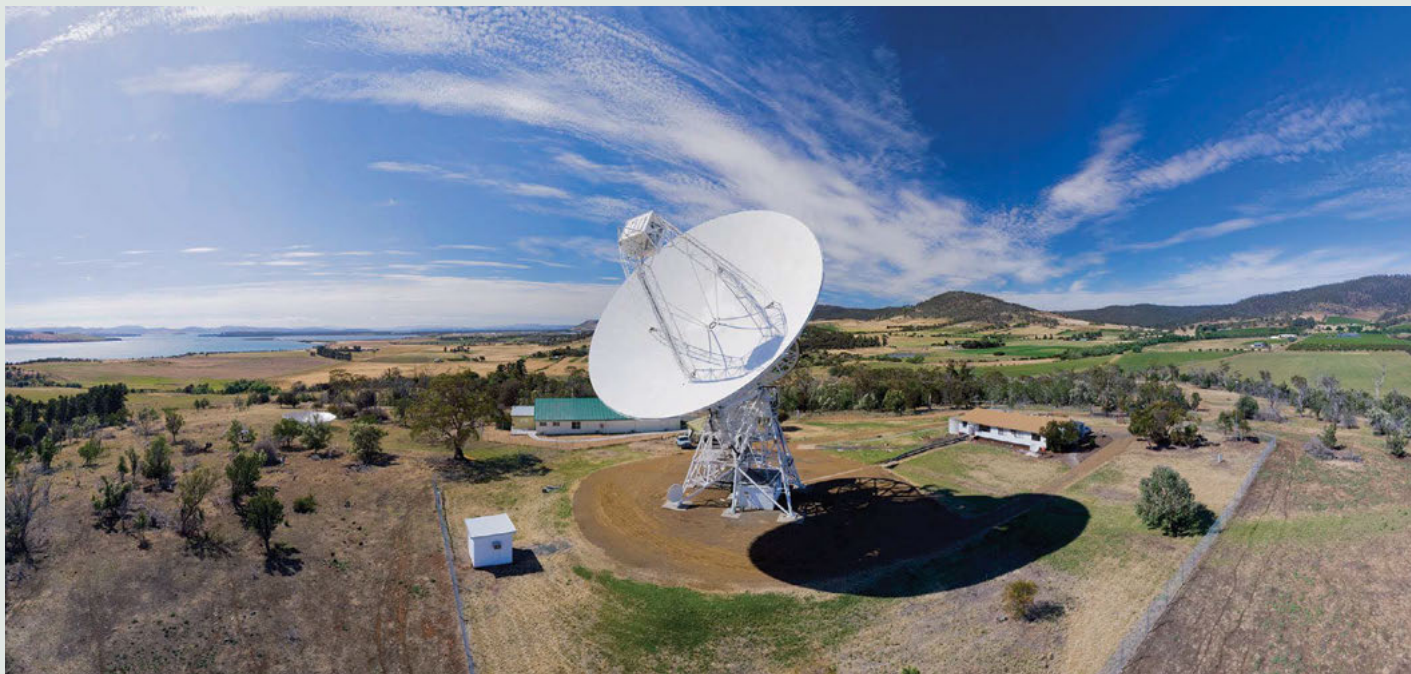
Today's radio telescopes are far more sensitive – and more susceptible to interference from radio waves generated on the Earth. So precautions are taken. International agreements ban a handful of radio frequencies that could swamp intergalactic signals – crucially the frequency at which hydrogen broadcasts

(around 1,420 megahertz). There are also radio quiet zones, such as the 34,000 square kilometres to protect the Green Bank and Sugar Grove telescopes in West Virginia, US.

The world's largest single aperture radio telescope, the 305 metre wide Arecibo dish in Puerto Rico, takes advantage of geology to find some quiet – it is located in a natural limestone sinkhole. Its work includes searching for extraterrestrial intelligent life, and it is the home of the citizen science project *seti@home*.

WHEN HE SPOTS STRANGE BLIPS IN HIS DATA, HE DRIVES AROUND THE AREA WITH A PORTABLE RADIOMETER TRYING TO TRACK ITS SOURCE.

But telescopes in more populated areas are vulnerable, as Petroff discovered at Parkes. In 2011, then-Swinburne PhD student Sarah Burke Spolaor found strange new signals in old data. These signals, which she called perytons, had to have come from Earth because they were seen across the whole telescope – not only in one little spot as is the case with bursts



Tasmania's 26-metre Mount Pleasant telescope. It is built in a valley near Hobart airport, and must contend with radio interference from local residents and businesses. CREDIT: JIM LOVELL

from deep space. Then three new perytons were picked up in one week in January 2015, mostly thanks to new, faster data processing software. In addition to this a radio frequency interference monitor, installed at Parkes the month before, picked up bursts of radio waves at the frequency of 2.5 gigahertz – exactly that which microwaves use – and at exactly the same time as the perytons were recorded. The peryton mystery was solved.

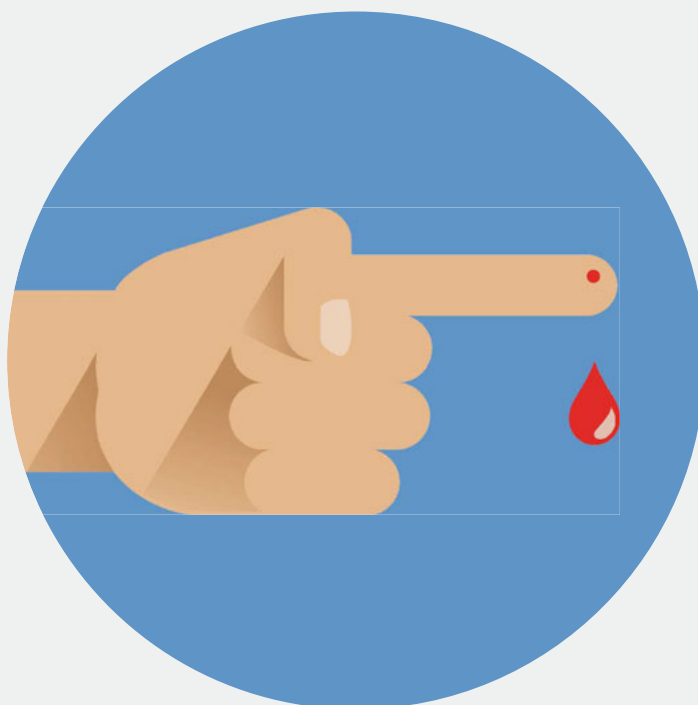
Petroff is not the only one to have traced radio signals to microwaves. John Dickey is director of the 26-metre Mount Pleasant telescope that sits in a valley 20 kilometres east of Hobart, Tasmania. When he spots strange blips in his data, he drives around the area with a portable radiometer trying to track its source. He once found a lumberyard drying logs in massive industrial microwaves. Dickey worked out a compromise with the business. “There’s a lot you can do with goodwill in the community,” he says.

Sometimes, though, goodwill doesn’t cut it. Astronomers at the 45-metre telescope at the Nobeyama radio observatory in Nagano, Japan, have tried to detect waves emitted by vibrating complex organic molecules in deep space – which may be related to the formation of life. Unfortunately, the radio frequency those molecules emit exactly matches the frequency used by car-mounted anti-collision radar systems. The car radar swamps any signals from space. “Of course, the car industry is super big in Japan so literally nobody’s supporting us!” says Masao Saito, director of the Nobeyama observatory.

Nevertheless radio-quiet areas can still be found. Murchison Shire in Western Australia, home to the Murchison Widefield Array, has around 110 people living in an area half the size of Tasmania. But the new gold standard for radio astronomy will be the Square Kilometre Array. Its construction in remote radio quiet zones in Western Australia and South Africa is billed to start in 2018. Until then, Dickey and his team will stay vigilant for stray microwaves in the Tasmanian countryside – while Petroff has once again turned her attention from the staff kitchen to signals from deep space. 🍷

BY THE NUMBERS

YOUR VIRULENT PAST



ONE DROP

The amount of blood a new technology, called VirScan, needs in order to identify all the viruses a person has been exposed to over the course of his or her life. Traditional blood tests can only detect one virus at a time.

25

The cost of the test in dollars.

206

The number of virus species detected by VirScan, including HIV and hepatitis C.

93,000

The number of short pieces of viral DNA the researchers synthesised to develop the test.

10

The average number of virus species volunteers testing VirScan technology were exposed to. One couple clocked up a whopping 84.



LIFE SCIENCES

The secret signal in a peacock's tail

Peacocks use their tail feathers to emit a sound so low-pitched humans can't hear it. BELINDA SMITH reports.

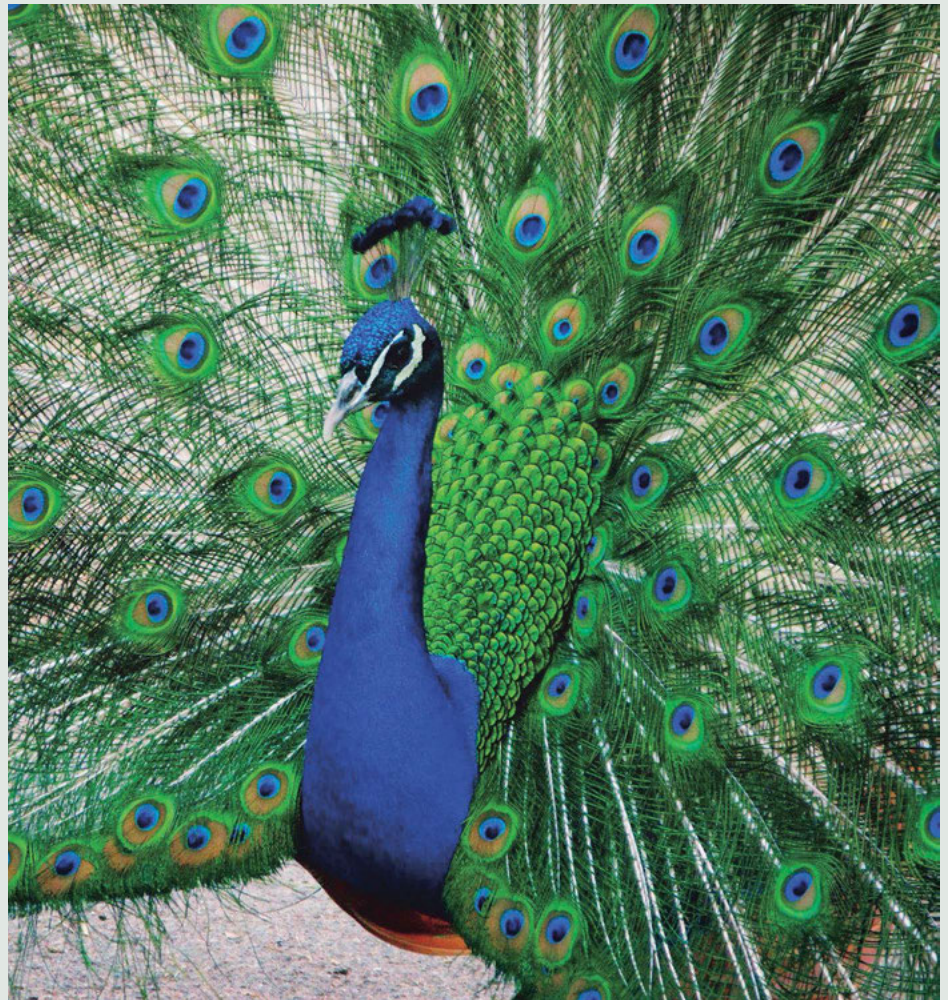
With its shimmering blue and green tail plumage, the peacocks display is one of the most dazzling sights in the animal kingdom. But it turns out there's more to the display than meets the eye.

Reporting in the journal *Animal Behaviour*, Angela Freeman and James Hare at the University of Manitoba, Canada, found that when peacocks fan their tail in a mating display, the rustling feathers generate a low frequency but far-reaching noise called "infrasound". That's too low for humans to hear. But it turns out peahens can. They may use it to spruik their show to audiences far away.

Hare got suspicious when, while visiting a Winnipeg Zoo, he noticed a lone peacock shaking his feathers and displaying his tail at a bare concrete wall. The peacock couldn't see its own reflection, so what was the point? Hare had a hunch it might have something to do with sound.

So he returned to record the sounds of rustling peacock tails. With his own ears, he could hear the high pitches of the rustling tail but below that, the recorder picked up something inaudible to humans: infrasound frequencies of less than 20 hertz. Intrigued, Freeman and Hare tested to see how the peacocks reacted to these different sounds. If they played back only the higher frequency rustling, they got little reaction. But playing back the infrasound made the peacocks and hens more active and alert.

Zoologists have known for years that elephants, whales and crocodiles can communicate by making low-frequency rumblings in their larynx. But evidence



A peacock's splendid tail is only one of its mating strategies. CREDIT: CARRIE KING / GETTY IMAGES

for infrasound communication in birds was patchy. Capercaillie grouse are known to make these sounds. Pigeons and chickens can perceive them. But peafowl are the first bird species shown to both make and hear infrasound.

INFRA-SOUND MAY BE THE PEACOCK'S SECRET CALL, A WAY OF SIGNALLING ITS WHEREABOUTS TO PEA-FOWL WITHOUT ALERTING PREDATORS.

So why, given the peacock's flashy tail and loud high-pitched hoots, would they bother?

Freeman thinks of infrasound communication as an accessory to the main show: "A peahen can only see a peacock if he's in view. But acoustic signals — which travel quite far — are being

used to signal to individuals out of view, we think."

The peafowl's natural habitat of dense, bushy jungle would frequently obscure peacocks, even when they are nearby. Low frequency sounds travel further than those of high frequencies. By pairing infrasound with its high-pitched calls, the peacock has all its sonic bases covered. "A good sexual signal is one that works well at short and long distances," says Andy Bennett, an animal behaviour expert at Deakin University in Geelong.

Bennett points out that larger tails can often attract more females, but "by making yourself gaudy or extravagant, whether that be in colour or size or sound, you also increase your risk of predation". It may be that infrasound is the peacock's way of signalling its whereabouts without alerting predators. ©



EARTH SCIENCES

The most ancient evidence of life on Earth?

Ancient bacteria in Pilbara rock are merely volcanic minerals, scientists say.
BELINDA SMITH reports.

Are they the oldest evidence of life on Earth or quirky crystals? For decades scientists have been arguing about the Apex chert microfossils found in the Pilbara region of Western Australia. The sceptics now claim to have delivered the knockout punch.

David Wacey and colleagues from the University of Bristol and University of Western Australia carefully sliced open some of the 3.46-billion-year-old ‘microfossils’ and found they are just unusually shaped slivers of volcanic material.

Their work has been published in the *Proceedings of the National Academy of Sciences*. “Our work solves a major controversy and removes this particular piece of evidence for life on the early Earth,” Wacey says.

But not everyone is convinced.

The story begins in the 1980s in the Pilbara – half a million square kilometres of dry rocky West Australian land that contains some of the Earth’s most ancient rock formations. During a prospecting trip near the town of Marble Bar, University of California paleobiologist, J. William Schopf, collected samples of a fine-grained sedimentary rock called chert.

Under a microscope he saw filament-like structures that looked like tiny segmented worms. Writing in *Science* in 1987, he described them as “dark-brown, carbonaceous, filamentous microfossils” of “about three micrometres in diameter and 30 micrometres to 40 micrometres in length”.

He compared them to cyanobacteria,

cells that will join end to end to form a filamentous structure. Analysing their chemical composition, he found them to be carbon rich – further evidence that they were indeed microfossils. They were dated at 3.46 billion years old and became enshrined in textbooks as the earliest known life.

Enter Oxford University paleobiologist Martin Brasier. In 2002 he re-examined the samples and pointed out that the Pilbara’s volcanic past provided perfect conditions for silicate minerals to thread themselves into filaments. The ‘cells’ were probably bits of volcanic glass.

Schopf had no trouble with the fiery origin of the fossils: his riposte was the bacteria were thermophiles – capable of living in hot, inhospitable environments such as hydrothermal vents. To settle the question, Brasier’s team decided to slice the filaments to examine their internal structure.

Schopf’s specimens were housed at the Natural History Museum in London which doesn’t take kindly to its specimens being sliced open. So Wacey – Brasier’s long-time collaborator – returned to the Pilbara to collect more rocks. “Fortunately we know the field area very well and we were able to collect material identical to the Schopf-type material,” Wacey says. “We were then free to apply any technique we wanted to it!”

Wacey used a technique common in making silicon chips, but new to palaeontology: a focused ion beam. It could cut an ultra-fine 10 nanometre thick line – fine enough to slice through the middle of the filaments.

Those slivers showed the carbon-rich ‘cell walls’ were made of glassy silicates – including mica and vermiculite. They contain large amounts of barium, typical of rock structures formed in hot, wet conditions.

The silicates also contained layers of carbon, but Wacey has an explanation. Vermiculite is sticky and would gradually have accumulated a carbon coating.

His theory is the filaments formed in a volcanic environment when wet mica grains heated and expanded rapidly. As they pushed water out, they left tiny cell-like segments that joined together.

Any hydrocarbons floating around would stick to the silicate surface and then fossilise over time, leaving what look like segmented “worms”.

“I think it’s a very interesting study,” Schopf says. “But it’s flawed.”

He’s not convinced the specimens Wacey collected were the same as his original Apex chert. “No one asked me exactly where I got my specimens from,” he says – information he says he would happily share.

It’s easy to mistake mineralised filaments for his microfossils, Schopf says. In a study that appeared in *Nature* in 2002 he examined 120 or so original Apex chert microfossils – “every doggone specimen” – with a technique called laser-Raman spectroscopy, which maps a chemical’s distribution through a sample. Schopf saw no vermiculite-like material of the sort that Wacey found.

“We don’t know how many specimens were analysed or how many didn’t have that vermiculite-like material,” he says.

So if Schopf’s microfossils are indeed expunged from the record, would that change what we know about life on a young Earth?

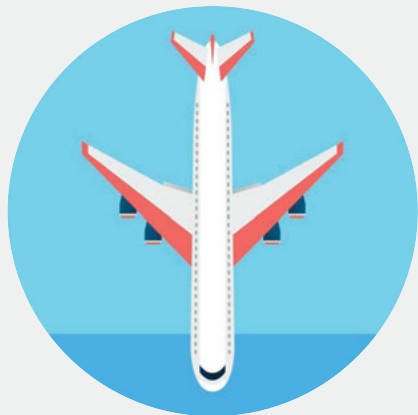
Not really, Wacey says: “There have been lots of recent discoveries of microfossils in rocks not much younger” – only 20 million years or so – “than the Apex chert.” ☺



The worm-like shapes in the rock are described in textbooks as the oldest form of life ever found on Earth. But not everyone is convinced. CREDIT: UNIVERSITY OF BRISTOL

IN BRIEF

MH370'S FINAL NOSEDIVE



A TEAM OF MATHEMATICIANS has suggested the reason no trace was found of missing Malaysia Airlines flight MH370 is because it nosedived into the Indian Ocean at a perfect 90-degree angle.

The theory is proposed by Goong Chen and his team of mathematicians at Texas A&M University's Qatar campus in a paper published in *Notices of the American Mathematical Society*.

The mathematicians used applied mathematics, computational fluid dynamics and numerical simulations to solve the so-called "water entry" problem. They concluded that a vertical or very steep angle would result in the least amount of force or pressure and would explain why no debris or oil from MH370 was found.

Chen said the wings would have broken off almost immediately and, along with other heavy debris, sunk to the bottom of the ocean, leaving little or no trace. "Forensics strongly supports that MH370 plunged into the ocean in a nosedive," he said.

— COSMOS EDITORS



SPACE

The search for planets beyond Pluto

Some scientists are convinced more planets exist in our Solar System.

By RICHARD A. LOVETT.

Not many years ago, the idea our Solar System might contain planets beyond Pluto would have been considered science fiction. But now, astronomers are beginning to wonder. As *Cosmos* went to press, NASA's New Horizons spacecraft was just days away from capturing our first close-up view of Pluto – and the more we study the dwarf planet, the less lonely it appears. Might the mission provide new hints that as yet undiscovered worlds lurk on the far edge of the Solar System?

We already know Pluto isn't entirely alone. In the mid-2000s four more distant worlds were discovered. One, Eris, is around Pluto's size. Three others – Makemake, Haumea and Sedna – are 40% to 60% the size of Pluto. All are in a distant region known as the Kuiper Belt.

These colleagues are also the reason Pluto was demoted from planet to dwarf planet in 2006. Part of the criteria for being a planet is that an object must sweep its orbit clear of other large objects. But the elliptical orbits of those distant worlds skim Pluto's orbit.

And they are likely just the tip of the iceberg, many astronomers argue. Alan Stern, principal investigator for the New Horizons mission and planetary scientist at Southwest Research Institute in Boulder, Colorado, thinks there could be hundreds more large objects on the edge of the Solar System waiting to be found.

These far distant objects receive so little sunlight it would be all but impossible to pick them out by telescope. Stern argues it is Pluto itself – and in particular, its largest moon, Charon – that provides the biggest clue that other large bodies are

out there. Since 1978 it's been known that Charon – which is roughly the size of Makemake, Haumea and Sedna – orbits Pluto.

In 2005 astrophysicist Robin Canup, also at the Boulder institute, published a study in *Science* that used computer simulations to show that early in Solar System history Charon had been an independent traveller that was captured by Pluto after the two collided.

What are the chances these two objects would ever meet, given the vast size of the outer Solar System? If Pluto and Charon were the only large objects there, Stern has calculated it would take 10,000 times the age of the entire Universe for it to become likely the two would cross paths. But if you had "1,000 Pluto-sized objects" in the region, then the meeting becomes more probable said Stern at a meeting last year of the American Geophysical Union in San Francisco.

Other scientists agree with Stern's calculations. One is Carlos de la Fuente Marcos, an astrophysicist at the University of Madrid, Spain. In a pair of 2014 studies in the *Monthly Notices of the Royal Astronomical Society*, his team looked at the orbits of the 13 extreme trans-Neptunian objects (planetoids whose orbits carry them at least five times farther out than Neptune).

These bodies are so dim and distant it's hard to be sure of their size. But similarities in their orbits suggest they may have been shepherded into their current paths by gravitational interactions with much larger bodies.

According to de la Fuente Marcos's computer models these extreme trans-Neptunian orbits may be revealing the presence of not one, but two objects that are more distant than Pluto – and perhaps much larger. He says not-yet published calculations suggest these planets might be "super Earths", two to 15 times larger than our own planet.

His team is not claiming to have discovered new planets. "Our studies are theoretical: statistics and simulations," he says. But when it comes to understanding the orbits of these distant bodies, he says, "this is the most simple and straightforward explanation." ☺

We ask researchers to tell us about their discoveries and to explain why they matter.

LAB TALK



LINDEN SERVINIS is a materials scientist at Deakin University in Geelong.



Super-strong material can be even stronger

When it comes to high-performance vehicles such as Formula 1 racing cars, lighter is better. But components made from metals such as aluminium are already about as light as they'll ever get.

Enter carbon fibre composites – tough plastics reinforced by an internal mesh of carbon fibre threads. The material is about a third the weight of aluminium with strength that matches steel. That might sound impressive, but there are still many gains to be made. Theoretical calculations estimate that individual fibres within the material are performing at only 10% of their potential strength. I aim to bring that figure up.

A closer view of carbon fibre composites under a microscope reveals the important components that make up the structure: the individual fibres, each one 100 times smaller than the diameter of a human hair, are surrounded by a thin layer of epoxy adhesive, which is then set in a resin reinforcement called the matrix.

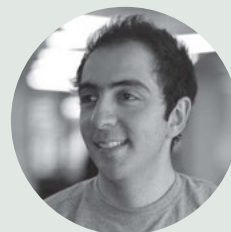
It's the chemical bonds between the fibres and surrounding resin – called the interface – that give carbon fibre composites their super strength. If the resin attaches nicely all the way along a carbon fibre, the composite will be very strong. But when there are only a few connections, the bond is weak and microscopic cracks can appear in the matrix around the fibres. This weakens the structure and can cause what we call “permanent failure” – in other words, an unfixable break.

I discovered that large sections of the carbon fibre surface, which were previously thought to be chemically inert, are actually quite reactive. This means we can chemically graft molecules on to the carbon fibre surface that will react with the resin matrix and, like “molecular nails”, firmly anchor the fibre into the resin.

We don't need to add many of these nails to increase composite strength – preliminary results show that the presence of only very small quantities of these molecular nails (a few parts per million) almost doubled the strength of the interface connection. This shows the impact atomic scale bond formation can have over composite performance, with many more unexplored chemistry techniques waiting in the wings. Maybe one day we'll bring that strength percentage close to 100. ☺

PAPER: A novel approach to functionalise pristine unsized carbon fibre using in situ generated diazonium species to enhance interfacial shear strength, *Journal of Materials Chemistry: A*, 2015, vol 3, p3360-3371.

ALI FATHI is a bioengineer at the University of Sydney.



A step forward for arthritis patients

Any invasive surgery comes with the risk of complications, from excessive bleeding to infection. And for the very old and frail, these complications can be fatal. So I developed an injectable hydrogel that could make many invasive medical procedures, such as knee replacements and dental implantations, unnecessary.

At room temperature, the hydrogel is liquid and can be injected through extra-fine insulin needles. But when it heats to body temperature, its structure changes – it can become as springy as cartilage or as smooth as skin. We're able to control this behaviour by adjusting the hydrogel recipe we use. It has two components: a synthetic polymer that becomes elastic or smooth as the situation demands and a peptide that programs the behaviour of the surrounding tissue.

Cartilage, for example, can be completely worn away in the joints of patients with arthritis. Without its protective cushioning, bone scrapes painfully on bone. This condition is usually treated by replacing the joint via surgery – a high-risk procedure for elderly patients.

By injecting our hydrogel into the joint space where cartilage once was, we can replace the lost padding between the bone surfaces.

More importantly, it also provides a nice scaffold for new cell growth. If we add peptides to the hydrogel to encourage the growth of cells that lay down more cartilage layers, the body will naturally heal itself. After three months or so the hydrogel will be completely and harmlessly absorbed, leaving fresh new cartilage in the affected joint.

The growth it promotes isn't limited to joints – I see it helping muscles and skin to regenerate too. It may prove popular with cosmetic surgeons! And we've run tests to make sure your body won't reject it.

We have patented the technology and I think it will be available in medical clinics around five years from now.

And who knows? If someday down the track you need arthritis treatment, it may just help you get back on your feet faster. ☺

PAPER: Elastin based cell-laden injectable hydrogels with tunable gelation, mechanical and biodegradation properties, *Biomaterials*, 2014, vol 35, p5425-5435.

TECHNOPHILE



Hanging out with geckos

Humans will be able to scale sheer glass walls – with gecko-inspired technology.
By CATHAL O'CONNELL.

Elliot Hawkes clings to the sheer wall of glass, the ground looming vertiginously below. He reaches higher, touches the hand-held pad to the pane. There is no feeling of suction, no sudden grip – frighteningly, it feels like the pad isn't going to stick.

But Hawkes knows it will stick when he hangs his weight on it. That's the hardest part, learning to trust it. He holds the pad to the glass, pulls down and – to his relief – a few postage stamps' worth of silicone rubber hold him up. He reaches with his other gecko-hand, eyes skyward...

Visitors to the reptile house are always amazed by the way geckos can cling to the sheer glass walls of their enclosure. Now, thanks to research by engineers at Stanford University in California, humans can do it too.

"The coolest thing about geckos is their feet, how they can adhere to almost anything," says Hawkes, a graduate student working on the project.

In the last decade, scientists have been studying the millions of tiny hairs that coat the underside of each toe on a gecko's foot. When the hairs are pressed to a surface, they stick to it due to the van der Waals force – a very weak electrical attraction that exists between all atoms and molecules. The dense coating of extremely tiny hairs maximises the contact area between the gecko's toes and the wall.

Scientists at the University of Massachusetts had previously found a way to replicate the gecko hairs by forming a surface bristling with wedge-shaped micro-scale ridges made from silicone rubber. When the ridges are pressed on to a surface, they splay out and the van der

Waals force kicks in. A new product based on the technology, Geckskin, is now in development.

Scaling up the gecko toe surface to enable human climbing was a huge challenge. In nature, any animal trying to use this adhesion effect has to be small, says Hawkes. "Nothing bigger than about 300 grams is able to climb with adhesion."

The Stanford team studied tokay geckos and discovered they did not evenly distribute their weight across the whole toe area. Because the nano-scale hairs are somewhat unkempt, the longer ones always take more than their share of the load.

An uneven mat of toe hair is an advantage for geckos, because it gives a good grip on a wall even if its surface is not perfectly smooth. But to hold a human, the team realised they'd have to design their Geckskin pads so that the weight is distributed evenly across the whole device. The adhesive surface is broken up into 24 postage stamp sized tiles, each bearing 416 microscale ridges. Each tile is attached to a special spring, to ensure each tile presses against the glass even if the surface is imperfect.

In late 2014, Hawkes became the first human to scale a sheer glass wall using the gecko-inspired climbing system. The device could support him – but the pads only work on smooth, clean surfaces. For now, scaling a brick or concrete wall is out of the question.

US Defense Advanced Research Projects Agency (DARPA) has shown interest in the material, as they can see an advantage in endowing their soldiers with the spiderman-like ability to climb walls.

The team is also working with NASA to develop arms that can grab on to the solar panels of dead satellites and tug them to safe orbits, a kind of satellite graveyard.

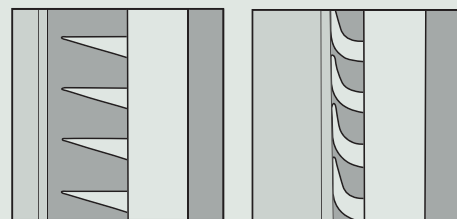
They have already used the same adhesives to build tiny robots with shoes so sticky they can lift or drag objects up to 100 times their own weight. "My Mum wants one to move her potted plants

around into the sun," says Hawkes.

The Stanford team has made great progress, but the gecko is still way ahead of us. While Hawkes could take a few steps per minute, a gecko can take 15 in one second.

"Just watching these little guys run up a wall, especially after I tried, you realise how cool, how smooth, how impressive the whole system is," says Hawkes. ☺

ILLUSTRATION: ANTHONY CALVERT



SILICONE RIDGES

A side view of the wedge-shaped ridges pressed on the glass. The ridges are not sticky if you simply hold them against a surface. Sliding causes the wedges to splay out. This exposes a much higher surface area, the van der Waals force kicks in and the wedges grip on.

GECKO GLOVE SPECIFICATIONS

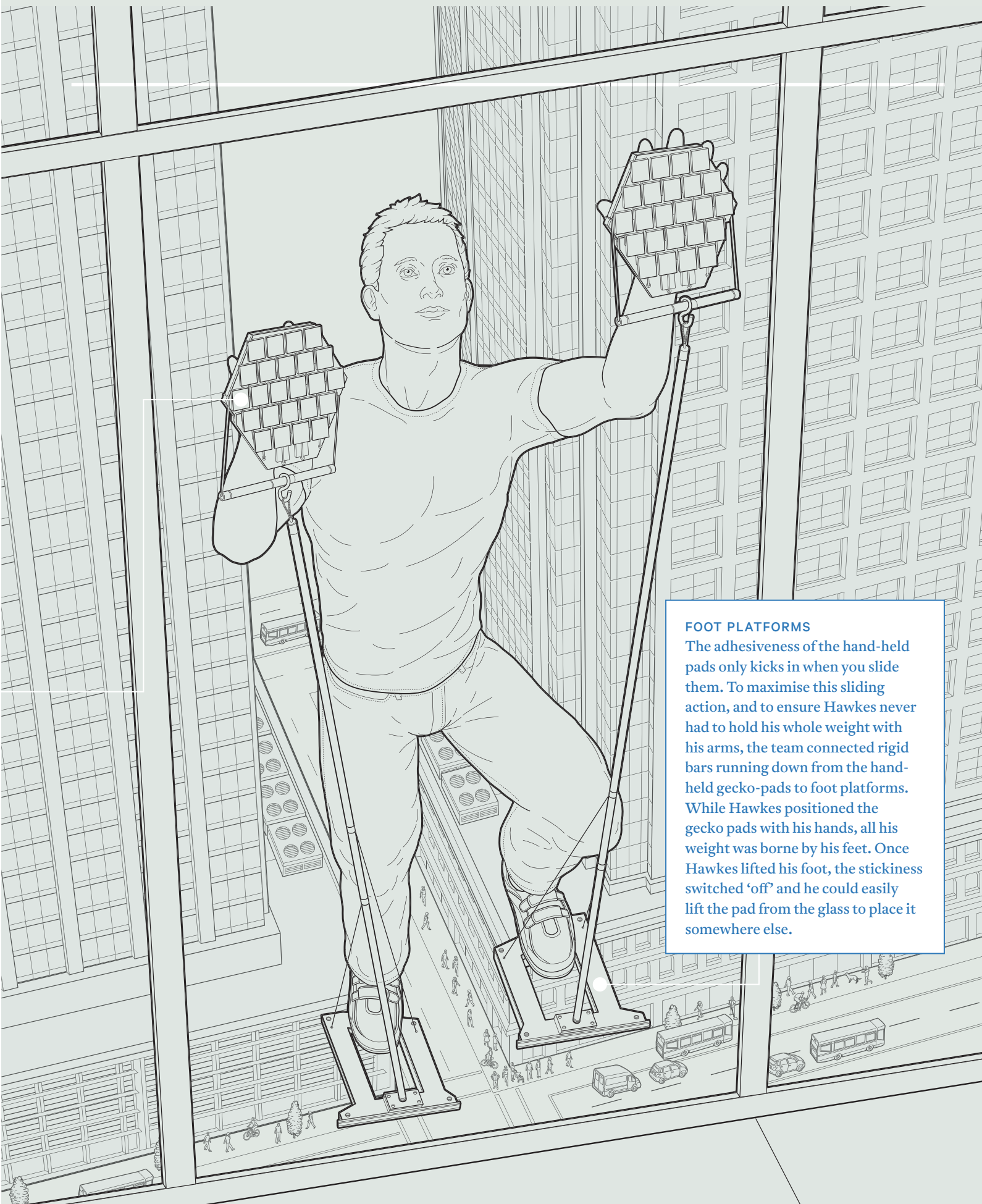
ADHESIVE AREA: 140 cm² per hand, spread across 24 postage stamp sized tiles

LOAD: Each tile (2.5 x 2.5 cm) can support 5 kg

MICROSTRUCTURE: 10,000 silicone ridges per glove, each 100 µm tall (the average diameter of a human hair)

STICKS TO: Almost any flat surface, including glass, polished metal, varnished wood and teflon

MATERIAL: Silicone rubber



FOOT PLATFORMS

The adhesiveness of the hand-held pads only kicks in when you slide them. To maximise this sliding action, and to ensure Hawkes never had to hold his whole weight with his arms, the team connected rigid bars running down from the hand-held gecko-pads to foot platforms. While Hawkes positioned the gecko pads with his hands, all his weight was borne by his feet. Once Hawkes lifted his foot, the stickiness switched 'off' and he could easily lift the pad from the glass to place it somewhere else.

CLIMATE WATCH



EARTH SCIENCES

Ice shelves and their worrying demise

The polar landscape is changing. **BELINDA SMITH** reports on the disappearance of ancient ice shelves.

Better book a cruise soon if you want to experience the awe-inspiring sight of Antarctic Peninsula ice shelves towering above you. They're 10,000 years old and crumbling, one by one.

Over the past few months, measurements from ice-penetrating radar suggest a chunk half the size of Tasmania could disappear within the next century. "We're watching a large-scale natural experiment unfold before our eyes," says Ala Khazendar, climate scientist at NASA's Jet Propulsion Laboratory in California.

And it's not only bad for tourism.

Ice shelves form long coastal sections of Antarctica and are also found in northern Canada and Greenland. They create an ever-changing coastline as they calve huge icebergs into the sea. Like the congealed plug on your toothpaste, ice shelves can also hold back seaward glaciers. Were Antarctica's ice shelves to disappear completely, sea level rises of tens of metres would obliterate the low-lying regions of the world.

Luckily, for the moment, Antarctica's collapsing ice shelves are confined to the continent's warmest, most northerly region, the Antarctic Peninsula. The peninsula sticks out from the Antarctic continent like a thumb from a fist, extending 1,300 kilometres towards South America. Its rocky islands are mostly

covered by an ice sheet up to 500 metres thick, the middle of which is drained by glaciers running east and west. The Larsen ice shelves, named for the British-Norwegian explorer and sea captain Carl Larsen, plug the east-running glaciers.

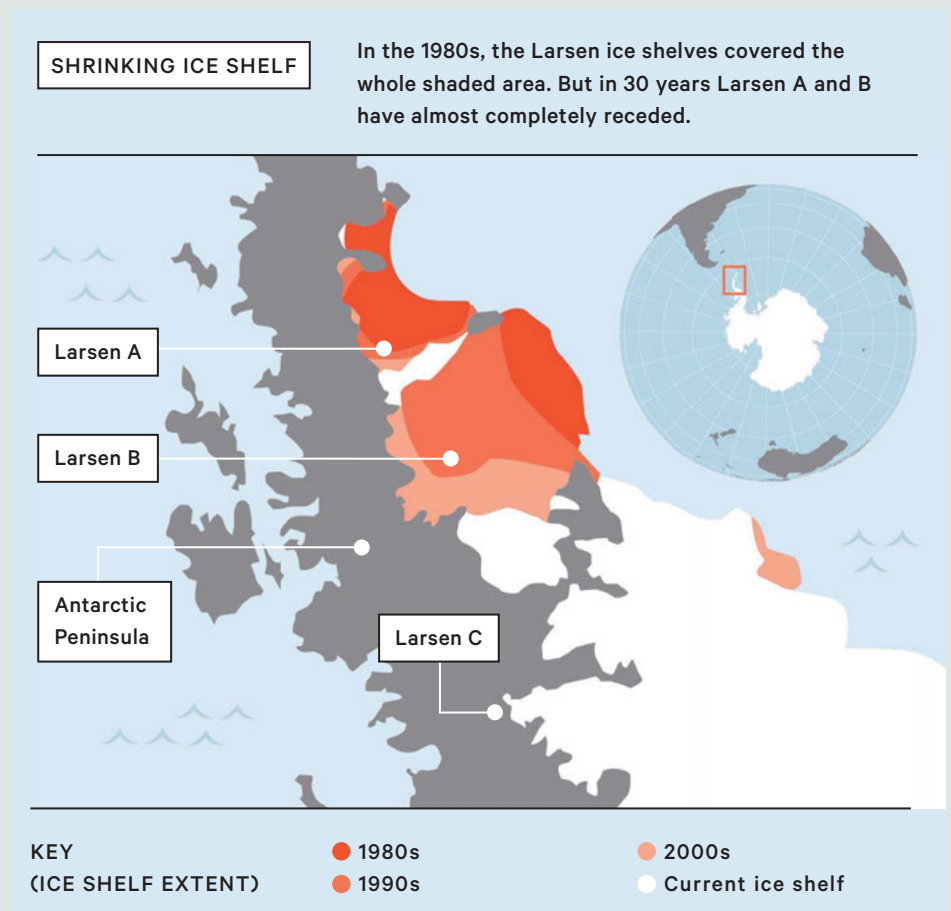
Just 20 years ago, seven ice shelves dotted the bayside edge of the peninsula. But in 1995, Larsen A – a 2,000-square-kilometre shelf at the northernmost tip of the thumb – collapsed completely in a single storm. Moving south, two thirds of Larsen B followed in 2002, and its remaining third looks set to crumble within a few years. Then there's Larsen C. At nearly 50,000 square kilometres – or half the area of Tasmania – it's the biggest of the peninsula's ice shelves. It's still standing – but for how long?

Like living organisms, ice shelves shed

and grow. They calve off massive chunks of ice that bob around the ocean as icebergs and are usually replenished by snowfall and tributary glaciers each year. But in a *Science* paper in April, climate scientist Fernando Paolo from the University of California, San Diego reported the balance has been lost: ice shelves are losing ice faster than they can regrow.

WERE ICE SHELVES TO DISAPPEAR COMPLETELY, SEA LEVEL RISES WOULD OBLITERATE LOW-LYING REGIONS.

From 1994 to 2003, ice shelves lost an average of around 25 cubic kilometres of ice per year. Then from 2003 to 2012, the ice loss ramped up more than tenfold to 310 cubic kilometres per year. At some



point, these ice shelves could reach a tipping point that sends them into sudden, dramatic collapse.

So why are ice shelves retreating? No surprise: global warming. But there's nothing simple about Antarctic weather patterns.

Out on Antarctica's thumb, the ice shelves are melting from warmer ocean currents flowing below, and warmer temperatures above. The peninsula's annual average temperature has increased by around 3 °C in the past 50 years – several times faster than the global average. Scientists are yet to crack the exact processes that have led to this localised warming, because across most of the continent's fist, winds are strengthening and increasing the spread of sea ice [see box].

Stronger westerly winds around Antarctica can be linked to the ozone hole and, perhaps, to global warming, Paolo says. While the ozone hole appears to be filling, he says “climate models suggest in the near future global warming will play a more important role in changing these winds”, which will increase ice shelf melt.

Using radar satellite imagery, Khazendar traces vast fractures in ice shelves. In a paper in *Earth and Planetary Science Letters* he and colleagues described one such crack creeping across what's left of Larsen B, 12 kilometres from its grounding line – where the ice shelf sits on rock. In addition, the flow of surrounding glaciers is also picking up pace. “It's basically haemorrhaging ice,” Khazendar says.

SO WHAT CAN WE DO? NOT MUCH – COLLAPSE OF THE REMAINING PART OF LARSEN B IS INEVITABLE.

Paul Holland, an oceanographer with the British Antarctic Survey, analysed 14 years' of aircraft radar, which he says is a way to “see through the ice”. Holland saw that Larsen C has been thinning too. He and his colleagues reported their findings in the journal *The Cryosphere*.

“Larsen B collapsed because it retreated past a critical point,” Holland says. “It's probably what will happen to

Two types of ice and why they matter

Ice shelves shrink while sea ice grows – what's going on?
BELINDA SMITH explains.

Last summer, the extent of Antarctica's sea ice reached a record high, denying supply ships access to Mawson station, and requiring all supplies to be flown in by helicopter. How can ice shelves be melting while sea ice is growing?

It's important not to confuse the two, says NASA climate scientist Ala Khazendar: “They both float – and that's about it.”

Sea ice is only a metre or two thick. Its extent depends mostly on wind strength, but also on ocean temperature, waves, currents and tides. Paradoxically, increased sea surface temperatures boost the extent of sea ice. Thinner ice layers break up and are spread more easily by winds.

The winds swirling around Antarctica have been blowing more strongly over the past few decades due to the steepening temperature gradient between the warming equator and the



An ice-breaker in the Ross Sea, Antarctica. Sea ice is proliferating despite global warming.

CREDIT: UIG-SI-001 / GETTY IMAGES

atmosphere over Antarctic, which has been cooled by the hole in the ozone layer. This has concentrated the winds into a tighter circle.

Down near the surface, strong southerlies, fresh off the West Antarctic ice sheet blow sea ice away from the coast to extend far into the Southern Ocean. But warmer winds from the north, such as those blowing onshore to the western edge of the Antarctic Peninsula, produce far less sea ice. ☺

Larsen C – we just don't know where that point is.”

While Larsen B held back 10 or so small glaciers before its collapse, Larsen C stems around 30. When it collapses, we can expect to see a few centimetres of sea level rise over a few decades. And while that may not sound much, the rapid onset will be tough to handle, Holland says: “We could deal with a rise of a metre over a 1,000 years, but over 100 years it would be really hard.” The Intergovernmental Panel for Climate Change's fifth assessment report has already forecast a 25-85 centimetre sea level rise by 2100.

The stakes are even higher in other parts of Antarctica, Khazendar says. Modelling suggests the far larger West

Antarctic ice sheet, which lies south of the peninsula, is tipped to cause up to four metres of sea level rise over the next 1,000 years. West Antarctica's Pine Island glacier, where temperatures are also rising, is the fastest melting glacier on the continent and already accounts for a quarter of the continent's ice loss.

So what can we do? Not much – collapse of the remaining part of Larsen B is inevitable, Khazendar says: “All we can do is diagnose and forecast.”

“I've been studying Larsen C for 10 years now and I've always been extremely sceptical about its collapse within a century,” Holland says. “But now I've accepted the possibility that it'll go within my children's lifetime.” ☺

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FROM THE FRONT LINE

Stopping a killer of horses

An equine physiologist identifies a marker for a deadly disease. By BELINDA SMITH.

“Prevention is better than cure” is a well-known medical maxim – and when a disease has no cure, prevention is essential. Laminitis, the second-biggest killer of horses today, is a crippling, incurable affliction in which the connective tissue between a horse’s foot and hoof begins to fall apart.

“Eventually a pony with laminitis will lie down and won’t get back up,” says Queensland University of Technology equine physiologist Martin Sillence. “The only treatment at the moment is painkillers – essentially palliative care.” So Sillence and his team set out to stop the disease from taking hold.

In the past it’s been difficult to identify the horses most at risk. First described by Aristotle 2,000 years ago as barley disease, laminitis afflicts all horse breeds and up to 30% of older ponies. And while it can be brought on by infection or

standing too long in transport trailers, it’s most commonly caused by a metabolic disorder that throws the animal’s insulin levels out of whack.

In humans, diabetes takes hold when the pancreas stops producing insulin. In horses, laminitis sets in when the horse’s pancreas goes into overdrive, pumping out insulin until it reaches toxic levels.

SILLENCE AND HIS TEAM DEVELOPED A DIAGNOSTIC BLOOD TEST THAT CAN CATCH HORSES WITH ELEVATED INSULIN LEVELS.

Sillence found the process starts in the gut. When healthy horses are given sugar, either as part of their diet or intravenously, they’ll have a normal insulin response – a burst from the pancreas, then back to normal within a couple of hours or less. In horses at the early stages of metabolic syndrome, intravenous sugar can also produce a normal insulin response.

But when these horses eat the same amount of sugar, their insulin levels go “through the roof”.

“We’ve found there are hormones released from cells in the gut called incretins that sense when glucose is on its way,” he says.

For a reason Sillence does not yet understand, some horses produce much higher levels of incretins, and this “turbocharges the pancreas”.

When a horse’s insulin levels stay high for long periods, cell receptors are activated in the foot that cause the cells to divide uncontrollably, weakening connective tissue between hoof and bone until they start to separate.

So Sillence and his team developed a diagnostic blood test that can catch horses with elevated insulin levels before outward symptoms start to show. Once a horse has been designated to be high risk, it can be placed on medication to stop its insulin levels from spiking.

And as with human diabetes patients,





Martin Sillence with Dove, a pony participating in clinical trials to treat Equine Metabolic Syndrome and prevent laminitis.

CREDIT: QUT MARKETING AND COMMUNICATION / ERIKA FISH

weight loss can help. Sillence's colleague Melody de Laat encouraged fat ponies to run up and down paddocks by placing a mechanised feed trough at each end that opened and closed at offset intervals. The ponies lost weight and their metabolism improved too.

"The work we've done has shown that we can actually prevent the disease with very good success when we can get insulin levels down," Sillence says.

The global market for laminitis prevention is around \$70 million a year – "small beans compared to human diabetes" Sillence observes – but not insignificant.

Preventing the disease before it takes hold will save horses and ponies from a shortened, painful life. ☺

Paint that lights up rusty patches

A new paint can identify metal corrosion. BELINDA SMITH reports.

A plane's livery is more than decoration or advertising – the thin layer of paint stops the plane corroding. But knowing where the paint is thinning, and where corrosion is starting to take hold, is no simple task.

So Vanessa Lussini, a chemistry PhD student at Queensland University of Technology, made a molecular sensor that lights up the sections of metal that need a touch-up – a big deal when you consider it can cost \$100,000 to repaint a plane.

"Corrosion is like a cancer to metal," Lussini says. When oxygen molecules latch on to the strong, light aluminium alloy most planes are built from they start eating away at the metal. Paint is an effective barrier, but it can chip or flake off and it also naturally degrades – accelerated by temperature and sunlight – so planes are regularly repainted. "Often only certain sections need to be painted because they are more exposed and degrade faster," Lussini says.

This is where Lussini's molecular sensor can help. It can be mixed in with paint to light up the sections or spots that need repainting.

The sensor molecule has two parts: one end plays the role of the glowing light bulb, and the other end is the switch that turns it on. The switch is a nitroxide, a man-made molecule with a rare property – it is a free radical that is relatively non-reactive.

"It's happy to dance by itself," Lussini says, "but when another free radical rocks up – like one produced by degrading paint – it grabs it."

When the nitroxide partners up with an oxidative free radical, it activates the fluorophore – the lightbulb – at the other end of the sensor molecule. Under UV light, the activated fluorophore glows brightly, showing engineers where they should paint.

So far, Lussini has added her sensor molecules into plastic films to test how long they last out in the elements, with

promising results. "You'd be surprised how quickly the plastic degrades in the Brisbane sun," she says. "The sensors stayed strong though."

The next step is to mix the molecules with paint. "The lucky thing is you can use a very low concentration," she says. "I'm talking about less than 0.1%. If we actually put too much in it seems to work less well, because of the free nitroxides." She explains that if too many nitroxide molecules are added they react with each other rather than catching the free radicals produced by the degrading paint.

THE MOLECULAR SENSOR CAN BE MIXED IN WITH PAINT TO LIGHT UP SPOTS THAT NEED REPAINTING.

Airlines wouldn't need to buy special paint – the sensor molecules work with commercially available paint. The colour of the fluorophore "bulb" can be changed too. So sensor molecules with green fluorophores could be mixed into the red paint Qantas uses, for example, while Aer Lingus might use orange fluorophores for their green sections.

The paint isn't limited to planes, Lussini says. It can be used on bridges or ships – any structure that needs paint to protect it from corrosion. "It has so many applications that affect just about everyone," she says. ☺



A sample of Lussini's molecular sensor that glows under UV light when it detects degrading paint. CREDIT: VANESSA LUSSINI

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FROM THE FRONT LINE

How to date a Russian cave lion

The oldest bone sample to be reliably carbon dated is 61,000 years old.
VIVIANE RICHTER reports.

In the summer of 2008, a resident of the Russian village of Anyuisk stumbled upon a stack of bones submerged in the muddy waters of the Malyy Anyui River. The bones made up the first near-complete skeleton of the now-extinct cave lion *Panthera leo spelaea* found in Russia.

The bones also came with preserved strands of hair and a curved claw – the first ever found for the species that roamed between 300,000 and 10,000 years ago. For millennia the remains were frozen in river sediment dating from the Pleistocene era. They were sufficiently preserved to allow the Russian Academy of Sciences to piece together the lion's morphology. But to find out when the lion died, the Russians contacted Vladimir Levchenko at the Australian Nuclear Science and Technology Organisation (ANSTO).

So how does one date an ancient lion?

Carbon atoms come in different varieties. The typical carbon nucleus

contains six protons and neutrons, but some have an extra neutron or two, producing carbon-13 and the radioactive carbon-14. Eventually, carbon-14 decays into the stable carbon-13 and carbon-12 isotopes. Working out ratios of the radioactive and stable carbons tells you the age of the sample. But the older the sample the less carbon-14 remains, and what is left becomes harder to find.

Most labs are only able to date carbon back to 50,000 years ago, but ANSTO's super-sensitive, low background accelerator mass spectrometry facility can pick up tiny amounts of radioisotopes – comprising a quadrillionth of the total atoms in a sample. That's the equivalent of finding one ant out of all the ants on Earth.

ANSTO chemist Fiona Bertuch extracted collagen from the lion's bones. She extracted the carbon from the collagen, the claw and hair samples and processed it into black graphite powder. Each powder sample was then placed inside a particle accelerator and turned into a particle beam, enabling Levchenko to count the radioactive carbon atoms as

The 61,000 year old lion's claw, successfully carbon dated by the Australian Nuclear Science and Technology Organisation.

CREDIT: ANSTO

they hit a detector. From their isotope ratios, he calculated the age of the lion's bone and claw to be a little more than 61,000 years old – making it the oldest bone sample to be reliably carbon dated. The work was published in *Quaternary Science Reviews*.

But the jury's still out on whether the hairs belong to the same lion. ANSTO's isotope ratios date them at around 28,700 years old. But this date could have been skewed by contaminants. The lion's hairs are hollow in order to trap air and insulate the animal against the cold. Microbes could have crept in long after the lion died, adding a younger stock of carbon-14. Levchenko plans to dissolve the hair's keratin to remove contaminants and get a more accurate date. If the hair does belong to the skeleton, this lion wore a stylish honey-copper coat. ☺



A lift for fish at Tallowa Dam

Scientists are going to great lengths to improve fish diversity in the Shoalhaven River. VIVIANE RICHTER reports.

Next time you run a tap, spare a thought for the thousands of migratory fish held up in the reservoir dams that provide us with drinking water.

Tallowa Dam stands 43 metres tall in the Shoalhaven River, New South Wales. The dam has supplied up to 30% of Greater Sydney's water during droughts. But "dams present a detrimental effect on fish migration", says Debashish Mazumder, environmental ecologist at the Australian Nuclear Science and Technology Organisation (ANSTO). Dams keep water in, but keep fish out – unbalancing the local ecosystem.

Some 96% of the fish in the Shoalhaven catchment are migratory. Plunging down a dam is easy for a fish. But unless you're a climber like the eel or can fling yourself over rocks like salmon, heaving yourself back upstream is impossible. Just 23 years after Tallowa Dam's construction, 10 of the Shoalhaven River fish species that must travel upstream to breed had

completely disappeared from the river.

One of these fish, the Australian bass – a favourite among anglers – was hatchery-bred and released into the upper dam to top up the population. But other species – including some of the bass's favourite prey fish – were not being replenished. So in 2009 the Sydney Catchment Authority built a "fish lift" – a 2,500-litre shuttling device, a bit like an apartment block elevator. It's not yet working at full capacity, but is expected to scoop and cart fish up and over the dam around 20 times a day.

To find out if the fish lift has re-balanced the food web, NSW Fisheries scientists collaborated with Mazumder to analyse invisible trackers in the fish by examining what the fish ate.

PLUNGING DOWN A DAM IS EASY FOR A FISH ... HEAVING YOURSELF BACK UPSTREAM IS IMPOSSIBLE.

Food contains natural chemical signatures called isotopes. These end up as building blocks for new cells, and those cells take on these signatures. Isotope variations of chemical elements have the same number of protons, but a different number of neutrons in the nucleus of the atom. For example, carbon has six protons in every atom, but can have six, seven or eight neutrons – producing carbon-12, carbon-13 or carbon-14 isotopes. Similarly, nitrogen, which normally has seven protons and neutrons, can also have eight neutrons.

Your personal ratio of these naturally occurring stable isotopes, known as carbon-13 or the nitrogen-15 varieties, will be similar to your favourite foods. If you only eat one species of fish, those ratios in your muscle will be close to of the that species. Mazumder describes isotopes as a "natural tracer".

So Mazumder's team analysed muscle samples of five species – the Australian bass, three species of its favourite prey and the introduced carp – collected above and below the Tallowa Dam before the fish lift fully kicked into gear.

Each sample was dried, ground to a fine powder and packed into tin capsules. The



The Tallowa Dam fish lift provides a mechanical shuttle to carry fish over the dam wall. CREDIT: CHRIS WALSH



Angler's favourite: the Australian Bass was reintroduced above the Tallowa Dam.

CREDIT: CODMAN

powder was incinerated in the capsules at 1,800 °C to form a gas. This gas was bombarded with electrons in an isotope ratio mass spectrometer, creating ions of different masses which were counted on a detector. The instrument was then able to calculate the ratios of different isotopes of particular elements.

Fish with greater variation in their carbon-13 or nitrogen-15 ratios cast a wider food web. Mazumder's study showed that while the fish downstream grazed widely, those above were stuck with a short set menu.

The results confirmed ANSTO's isotopic technology as a means to check up on the Tallowa Dam ecosystems, especially once the lift is in full operation. Mazumder anticipates the fish above the dam will soon be able to have a more balanced diet. ©



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“THESE STUDIES COULD BRING CARBS BACK INTO FAVOUR”

NORMAN SWAN — HEALTH



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BODY TALK



KATIE MACK
ASTRO KATIE



LAURIE ZOLOTH
PHILOSOPHER'S CORNER



ALAN FINKEL
INCURABLE ENGINEER

NORMAN SWAN is a doctor and multi-award winning producer and broadcaster on health issues.

BODY TALK

In defence of our daily bread

New evidence suggests carbs have been unfairly demonised.

I'M DISGUSTING to be with at a sandwich lunch. I peel apart the focaccia, pick at the filling for scraps of protein to assuage my hunger and then discard a plate piled high with unwanted carbs. All in the cause of a flatter abdomen and better health.

This behaviour is part of a backlash. In the 1980s when public health researchers demonised fat, they didn't foresee that we'd trade fats for unlimited sugar and fructose and bowls of white rice or pasta. The result was bigger bellies and ultimately type 2 diabetes.

The pendulum then swung back to reducing carbohydrate intake and boosting protein – protein is good at satiating appetite while helping to shed weight. Cheerleaders for this strategy included US doctor Robert Atkins and more recently US science writer Gary Taubes (author of *Good Calories, Bad Calories*).

In effect we have been subjected to huge changes in our diets for decades, with poor evidence to support the reason for the changes.

But over the last year or so, a series of studies led by Steven Simpson, director of the Charles Perkins Centre at the University of Sydney, has questioned our see-sawing dietary fads. These studies could bring carbs – or at least some types – back into favour. Their work has been published in respected journals such as *Cell Metabolism* and *Cell Reports*.

The Sydney researchers designed 25 lifelong diets for mice, which varied their ratios of fat, protein and corn-based carbs. The mice were free to eat as much of their assigned food as they liked. Some of the diets packed more calories per gram than others, so their total calorie intake varied.

What the Sydney scientists found was surprising. How long the mice lived was not connected to their calorie intake, but to the ratio of protein to carbs consumed.

The longest-lived mice in the best metabolic health – their heart doctors would have been happy with their blood lipid profiles, sugar, and insulin levels – were the ones eating more carbohydrates and less fat and protein. A low ratio of protein to carbs appeared to be key. The shortest-lived mice were either on a low protein, low carb, high fat diet or a high protein, high fat, low-carb diet, similar to the original Atkins diet. The mice on the Atkins-type regime were leaner, but the plumper, higher carb eating mice lived 30% longer.

The best diet balance of them all turned out to be what the mice selected for themselves – namely around 55% of calories as carbohydrates, around 23% as protein and 22% as fat. That happens to be pretty close to what we call the Mediterranean diet, which many studies have found to be associated with lower rates of type 2 diabetes and heart disease and a longer life expectancy.

So how does this ideal macronutrient ratio compare to the effects of calorie restriction? Many animal studies show that if you restrict calories by 30-40%, the reward is a 30% increase in lifespan. That's almost impossible to test in humans, although it is known that reducing calorie intake improves our cardio-metabolic health.

The Sydney group then decided to compare, head to head, the higher carbohydrate, lower fat and protein diet



to calorie restriction, again in mice, and to test their longevity and metabolic health.

The results showed that the free eating, higher carb mice lived as long as those on 40% calorie restriction, and were presumably happier too, even if they were a bit chunkier.

The carbohydrates in the diet, by the way, were not highly processed and contained little or no sugar, and the fat was low by human standards at 20%.

Now these were mice, not humans, so there's a limit to how far we can extrapolate. But the findings do suggest a high, relatively unprocessed carb diet is healthy.

The explanation? Simpson believes the ratio of protein to carbs is sensed by two yin-yang metabolic pathways known as mTOR and AMPK. At high protein ratios, the pathways optimise growth and reproduction at the expense of self-maintenance. At low protein ratios, the pathways flip. Complex carbs may also exert a benefit by maintaining a healthy microbial community in the lower bowel.

So have these findings made me a more pleasant companion at a sandwich lunch?

Not yet. But that's more about my inability to stop myself going back to the table for seconds and thirds. ☹

KATIE MACK is a theoretical astrophysicist who focuses on finding new ways to learn about the early Universe and fundamental physics.

ASTRO KATIE

Death in a vacuum

Of all the ways the Universe might die, vacuum decay is the most efficient.

EVERY ONCE IN A WHILE, physicists come up with a new way to destroy the Universe. There's the Big Rip (a rending of spacetime), the Heat Death (expansion to a cold and empty Universe), and the Big Crunch (the reversal of cosmic expansion). My favourite, though, has always been vacuum decay. It's a quick, clean and efficient way of wiping out the Universe.

To understand vacuum decay, you need to consider the Higgs field that permeates our Universe. Like an electric field, the Higgs field varies in strength, based on its potential. Think of the potential as a track on which a ball is rolling. The higher it is on the track, the more energy the ball has.

The Higgs potential determines whether the Universe is in one of two states: a true vacuum, or a false vacuum. A true vacuum is the stable, lowest-energy state, like sitting still on a valley floor. A false vacuum is like being nestled in a divot in the valley wall – a little push could easily send you tumbling. A universe in a false vacuum state is called “metastable”, because it's not actively decaying (rolling), but it's not exactly stable either.

There are two problems with living in a metastable universe. One is that if you create a high enough energy event, you can, in theory, push a tiny region of the universe from the false vacuum into the true vacuum, creating a bubble of true vacuum that will then expand in all directions at the speed of light.

Such a bubble would be lethal.

The other problem is that quantum mechanics says that a particle can ‘tunnel’ through a barrier between one region and another, and this also applies to the vacuum state. So a universe that is sitting quite happily in the false vacuum could, via random quantum fluctuations, suddenly find part of itself in the true vacuum, causing disaster.

The possibility of vacuum decay has come up a lot lately because measurements of the mass of the Higgs boson seem to indicate the vacuum is metastable. But there are good reasons to think some new physics will intervene and save the day.

One reason is that the hypothesised inflationary epoch in the early Universe, when the Universe expanded rapidly in the first tiny fraction of a second, probably produced energies high enough to push the vacuum over the edge into the true vacuum. The fact that we're still here indicates one of three things. Inflation occurred at energies too low to tip us over the edge, inflation did not take place at all, or the Universe is more stable than the calculations suggest.

“VACUUM DECAY IS THE ULTIMATE
ECOLOGICAL CATASTROPHE ...
NOT ONLY IS LIFE AS WE KNOW IT
IMPOSSIBLE, SO IS CHEMISTRY ...”

If the Universe is indeed metastable, then, technically, the transition could occur through quantum processes at any time. But it probably won't – the lifetime of a metastable universe is predicted to be much longer than the current age of the Universe.

So we don't need to worry. But what would happen if the vacuum *did* decay?

The walls of the true vacuum bubble would expand in all directions at the speed of light. You wouldn't see it coming. The walls can contain a huge amount of energy,

so you might be incinerated as the bubble wall ploughed through you. Different vacuum states have different constants of nature, so the basic structure of matter might also be disastrously altered. But it could be even worse: in 1980, theoretical physicists Sidney Coleman and Frank De Luccia calculated for the first time that any bubble of true vacuum would immediately suffer total gravitational collapse.

They say: “This is disheartening. The possibility that we are living in a false vacuum has never been a cheering one to contemplate. Vacuum decay is the ultimate ecological catastrophe; in a new vacuum there are new constants of nature; after vacuum decay, not only is life as we know it impossible, so is chemistry as we know it.

“However, one could always draw stoic comfort from the possibility that perhaps in the course of time the new vacuum would sustain, if not life as we know it, at least some creatures capable of knowing joy. This possibility has now been eliminated.”

To know for sure what would happen inside a bubble of true vacuum, we'd need a theory that describes our larger multiverse, and we don't have that yet. But suffice it to say, it would not be good. Luckily, we're probably reasonably safe.

At least for now. ☺



LAURIE ZOLOTH is a professor of medical ethics & humanities at Northwestern University, Chicago.

PHILOSOPHER'S CORNER

Is a trip to Mars ethical?

How do you decide whether putting human life at risk is the right thing to do?

FOR THE 21ST CENTURY explorer Mars would have to be the number one travel destination. If that's you, you might try your luck with Mars One, a privately funded mission to colonise Mars led by Dutch entrepreneur Bas Lansorp.

If you're selected, it's a seventh-month one-way only trip. The first four human volunteers are scheduled to blast off in 2026 in the hope of setting up a colony. Scientists, engineers and others in the space industry say the mission is not feasible. But it is the ethics of the enterprise that concern me here.

Some years ago I was among a group of bioethicists asked to ponder the morality of sending humans into space for several months or years.

At the time NASA was considering the idea of sending astronauts to Mars — with no real way of organising a flight home. (Since then NASA has developed plans for a three-year return trip to Mars in 2035.)

I told NASA that exploration in situations of terrifying and serious risk was not new.

Asking if human long-duration space flight is ethical means asking the same questions that Englishman Robert Falcon Scott *should* have asked before setting out on his doomed mission to the South Pole. What are the technical constraints

and what needs to be invented? What preparedness is needed and what is the cost? What information is needed for the crew to consent?

History tells us that Scott arrived at the Pole a month after Roald Amundsen claimed it for Norway. Scott died along with his entire company on the way home. They were hopelessly unprepared — taking French olives and raspberry jam and inadequate gloves. Amundsen by contrast learned survival skills from peoples who lived in the Arctic before setting out. Scott's example teaches us that bravery is not enough: realistic preparation is crucial.

The risks of long-haul human space flight have been known for years. In 2002 a NASA committee wrote a list. These included the health hazards posed by space radiation; the possibility that the crew could sabotage the mission — based on studies of isolated communities and the psycho-social issues that can arise; physiological risk, including bone and muscle loss in microgravity; and medical risk — including the difficulties of treating injuries and illness in space. Several years later, all these factors remain.

The Canadians, the European Union and the Japanese conducted studies of their own and reached the same conclusion. Space is the harshest possible human environment, exceeding conditions anywhere on the planet. Crucially, more is unknown about the physical and mental challenges of space travel than is known.

Assessing risk in a situation of utter unknowability is complicated. In the face of this uncertainty risk analysts have put forward the RABA concept (Risk Associated with the Best Alternative). A bad outcome of the best considered alternative might be easier to accept than charging in like Scott without adequately considering the risks. But there are limits to rational arguments about the risks of



space colonisation: we don't know what we don't know.

So what makes risk ethical? Historically it has been one thing: consent. The ethical considerations change if we think of the crew as military personnel. We expect soldiers to face considerable risk. And think of the pioneers who travelled to remote and desolate places with no thought of return.

SPACE IS THE HARSHTEST POSSIBLE HUMAN ENVIRONMENT, EXCEEDING CONDITIONS ANYWHERE ON THE PLANET. CRUCIALLY, MORE IS UNKNOWN ABOUT THE PHYSICAL AND MENTAL CHALLENGES OF SPACE TRAVEL THAN IS KNOWN.

So what did I advise NASA? Exploring space is an awesome enterprise — but it has to be done at awesome cost. The process has to protect the astronauts as much as possible. The mission must be done publicly for peaceful purposes, by free people, with the results considered common stock.

But before we set out we need a far-reaching public discussion of what space travel means to us — and what we are prepared to sacrifice for it. ☺

ALAN FINKEL is an electrical engineer, neuroscientist and the publisher of *Cosmos* magazine.

INCURABLE ENGINEER

**Batteries
can save
the world**

Developing renewable energy storage is the moral imperative of our age.

THE ENERGY REVOLUTION has begun. Almost daily reports trumpet price breakthroughs in solar and wind electricity while fossil-fuel generation facilities are disparaged as stranded assets.

Engineering advances have seen renewable electricity generation costs plummet so fast they are competitive with oil and gas, and giving coal a nudge. Yet they still represent less than 4% of global electricity production.

The biggest roadblock to the large-scale uptake of solar and wind electricity is their intermittency. We need storage systems for them to be useful. Storage that can supply whole countries in winter when — inevitably — for perhaps 10 days in a row the wind is still and the sun doesn't shine.

Developing large-scale storage systems is the key to converting our electricity production to zero-emission sources.

One possibility is pumped hydroelectric storage. In this approach, excess electricity is used to pump water uphill from a lower reservoir. When electricity is in short supply the pipe gates in the upper reservoir are opened, allowing a torrent of water to spin turbines and generate electricity.

The potential is huge. The world's biggest 'battery' is the pumped storage facility at Bath County, Virginia, with the

capacity to store 30,000 megawatt-hours of energy, enough to supply Los Angeles for 12 hours. This method far exceeds the global electricity storage capacity of all other storage forms combined.

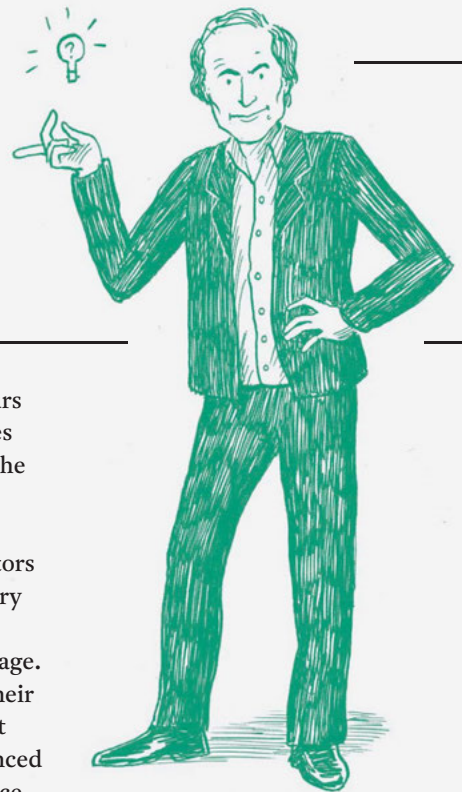
But change is on the way. Tesla Motors Corporation has been developing battery packs with ever greater storage to give their electric cars a competitive advantage. They are now committed to applying their battery know-how to store intermittent renewable energy. The recently announced Tesla Gigafactory is projected to produce 50,000 megawatt-hours of storage across five million, 0.01 megawatt hour lithium-ion battery packs annually in 2020.

Encouragingly, Tesla is not alone. Mercedes Benz is already selling home storage solutions and the Chinese automobile company BYD (Build Your Dreams) has announced plans for 34,000 megawatt-hours of annual battery pack production by 2020.

Not to be outdone, traditional battery manufacturers such as LG, Samsung, Panasonic and Toshiba are developing and supplying battery backup systems of up to 40 megawatt-hours each. Manufacturing efficiency has kept pace and pushed battery prices down fourfold in less than a decade, from \$1.3 million per megawatt-hour in 2006 to \$350,000 per megawatt-hour this year. This trend is likely to continue.

Around the world, in private and publicly funded labs, extensive research is being done to develop batteries based on magnesium, zinc or aluminium instead of lithium. These approaches might be even cheaper, and will relieve the pressure on lithium mining.

Storage technologies must not only compete on cost but also on their 'round-trip' efficiency. That is: start with electricity, store it, convert it back to electricity. For batteries, the round-



trip efficiency is 85%. For pumped hydroelectric storage it's more than 80%. These values are good enough to be extremely practical.

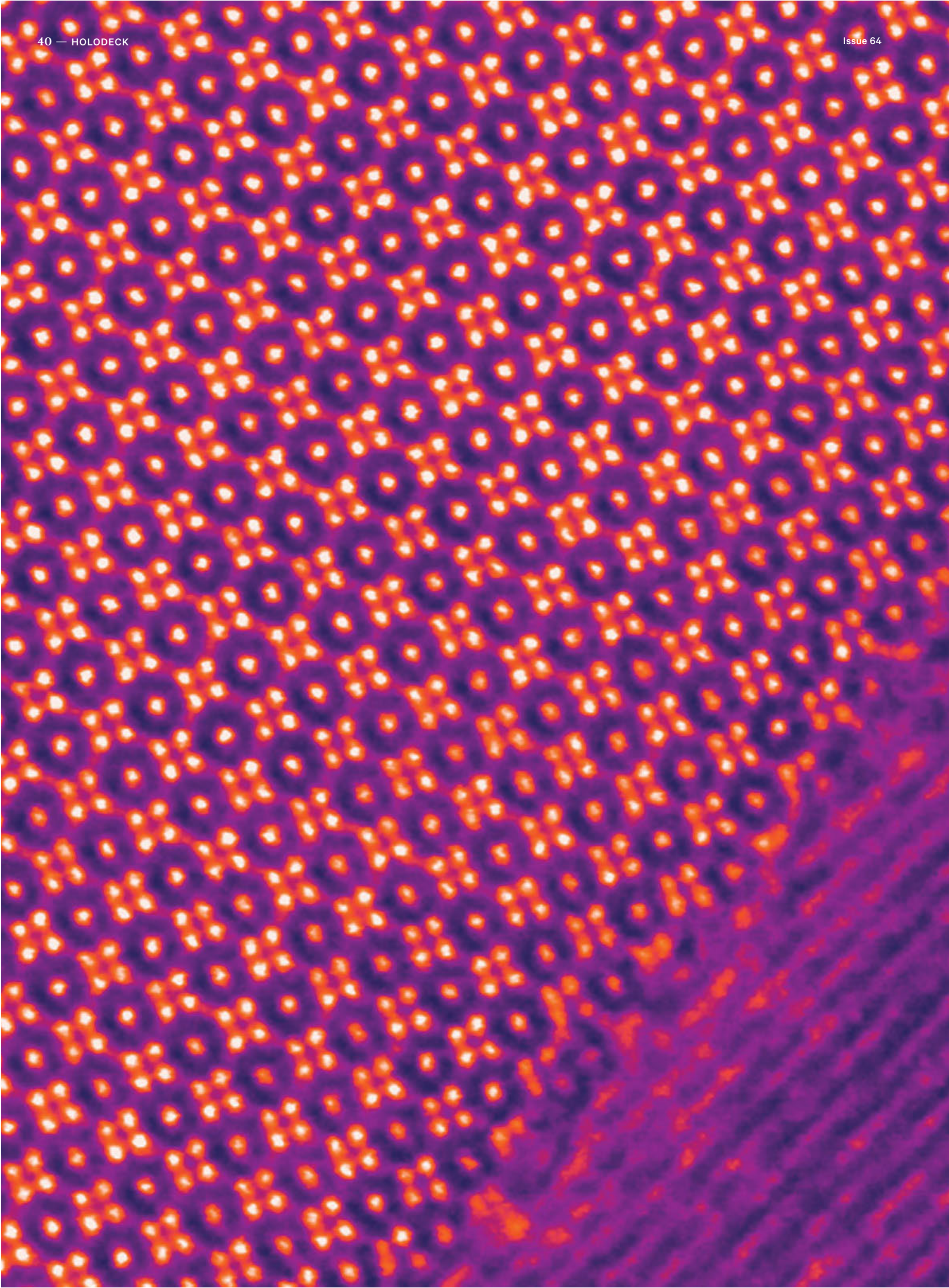
Hydrogen storage, in which electricity is used to split water into hydrogen and is then converted back to electricity, has the potential to be used at large scale in a turbine generator, or for a car's fuel cell.

But most hydrogen storage systems operate at 35% round-trip efficiency. A more respectable 50% round-trip efficiency can be expected in coming years.

Compressed air energy storage systems, in which excess electricity is used to compress large volumes of air that is subsequently released to drive an electricity generator, have occasionally been installed, but their round-trip efficiency remains less than 50%.

There is still a long way to go. To store the world's electricity requirements for 10 days would require 500 million megawatt hours — 10,000 times the projected annual production capacity of the Tesla Gigafactory in full swing. To get there we have to think big.

The message for governments is clear. Governments already use subsidies to encourage renewable electricity generation. It is time now to shift their investments to improving storage. ☻



HOLODECK:
COMPILED BY VIVIANE RICHTER

SEEING ATOMS

"Nothing exists except atoms and empty space."
— Democritus 460-370 BC.

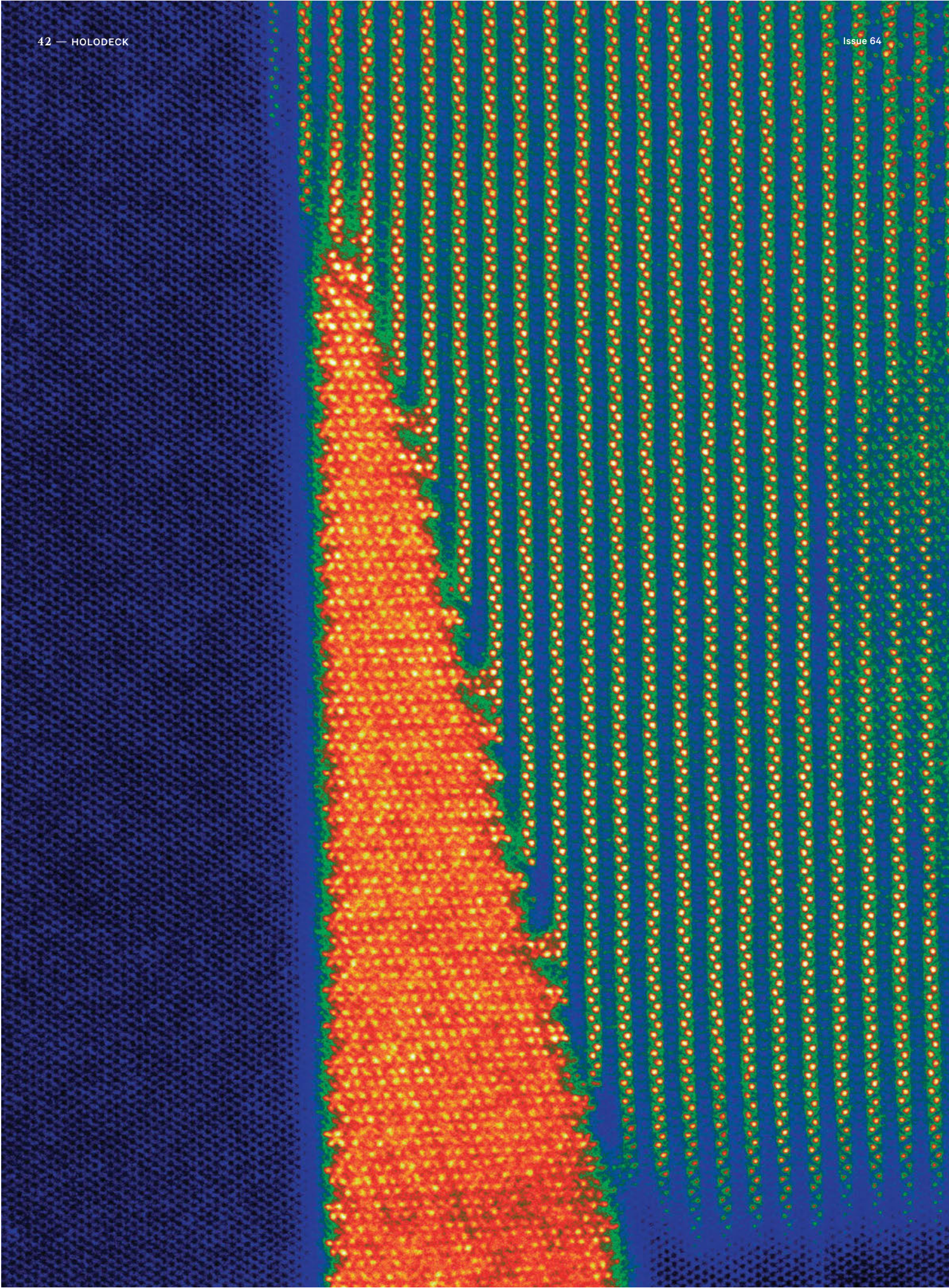
PERHAPS IT WAS THE WHIFF of baking bread that led Democritus to imagine that matter was composed of tiny, indivisible building blocks. Atoms, he called them, meaning something that cannot be cut.

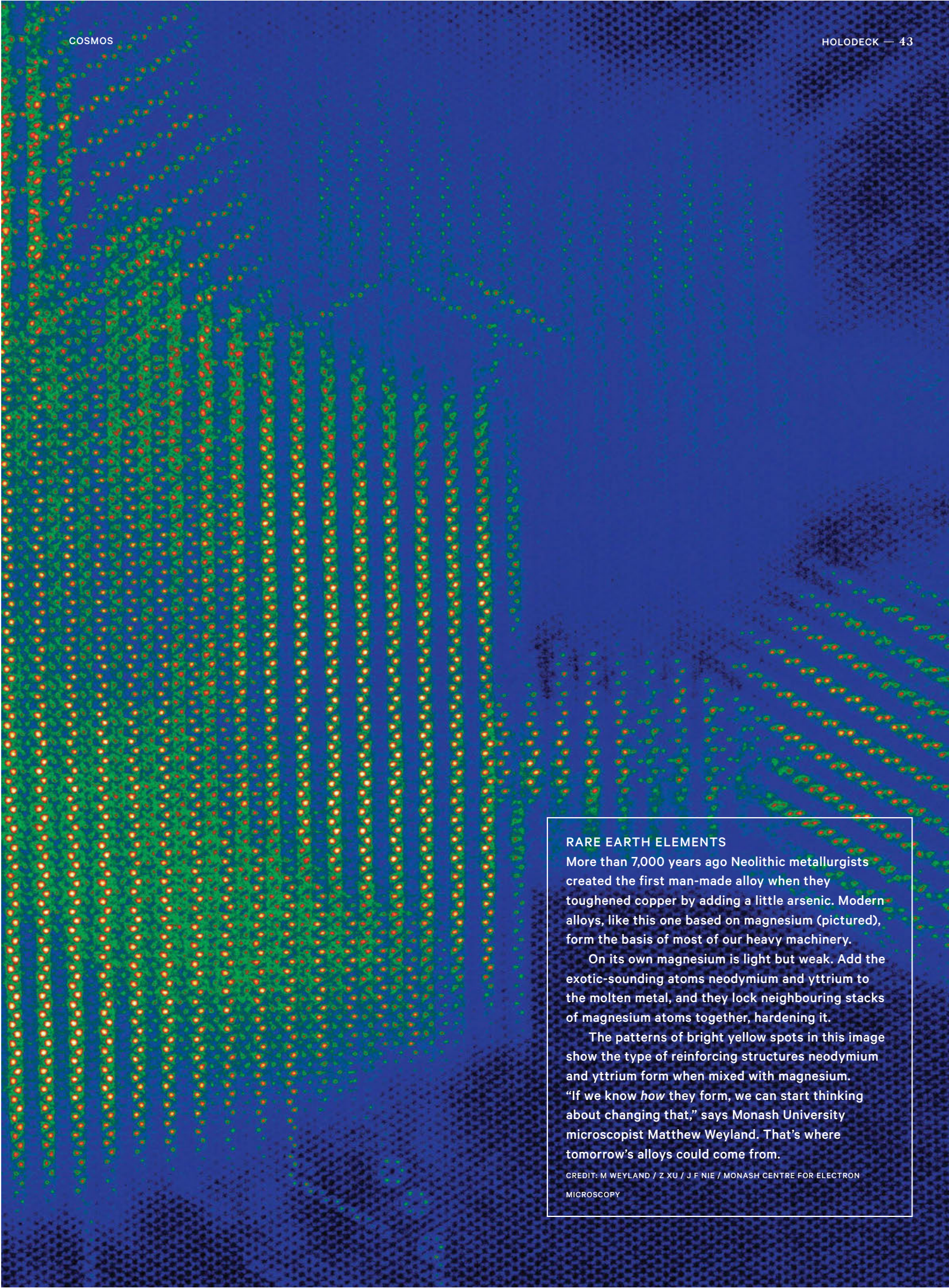
If only the Greek philosopher could take a peek through today's scanning transmission electron microscopes.

This image peers inside garnet, a semi-precious mineral found throughout Earth's crust, to see neat stacks of yttrium atoms. On the left, we're looking down the stacks; on the right we see the stacks side-on.

Some elements diffused throughout the garnet record the pressure and temperature at which the rocks around them formed. Read these patterns and you can read the Earth's geological history.

CREDIT: Q M RAMASSE / M SCHAFFER / SUPERSTEM LABORATORY, UK





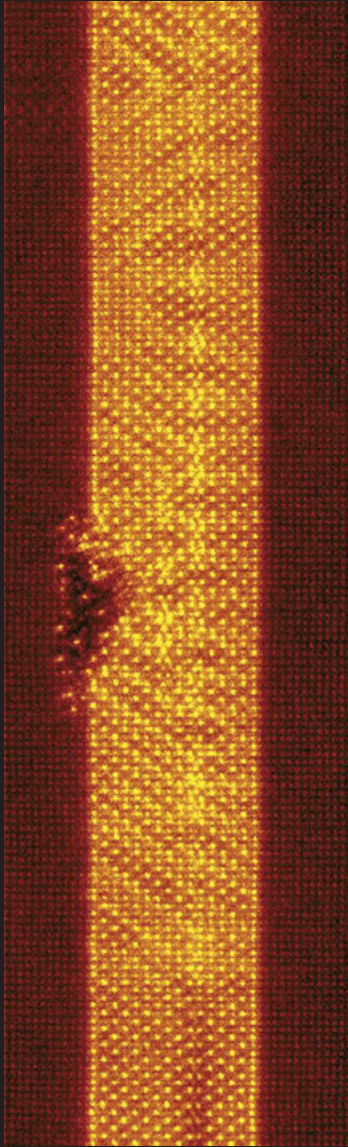
RARE EARTH ELEMENTS

More than 7,000 years ago Neolithic metallurgists created the first man-made alloy when they toughened copper by adding a little arsenic. Modern alloys, like this one based on magnesium (pictured), form the basis of most of our heavy machinery.

On its own magnesium is light but weak. Add the exotic-sounding atoms neodymium and yttrium to the molten metal, and they lock neighbouring stacks of magnesium atoms together, hardening it.

The patterns of bright yellow spots in this image show the type of reinforcing structures neodymium and yttrium form when mixed with magnesium. “If we know *how* they form, we can start thinking about changing that,” says Monash University microscopist Matthew Weyland. That’s where tomorrow’s alloys could come from.

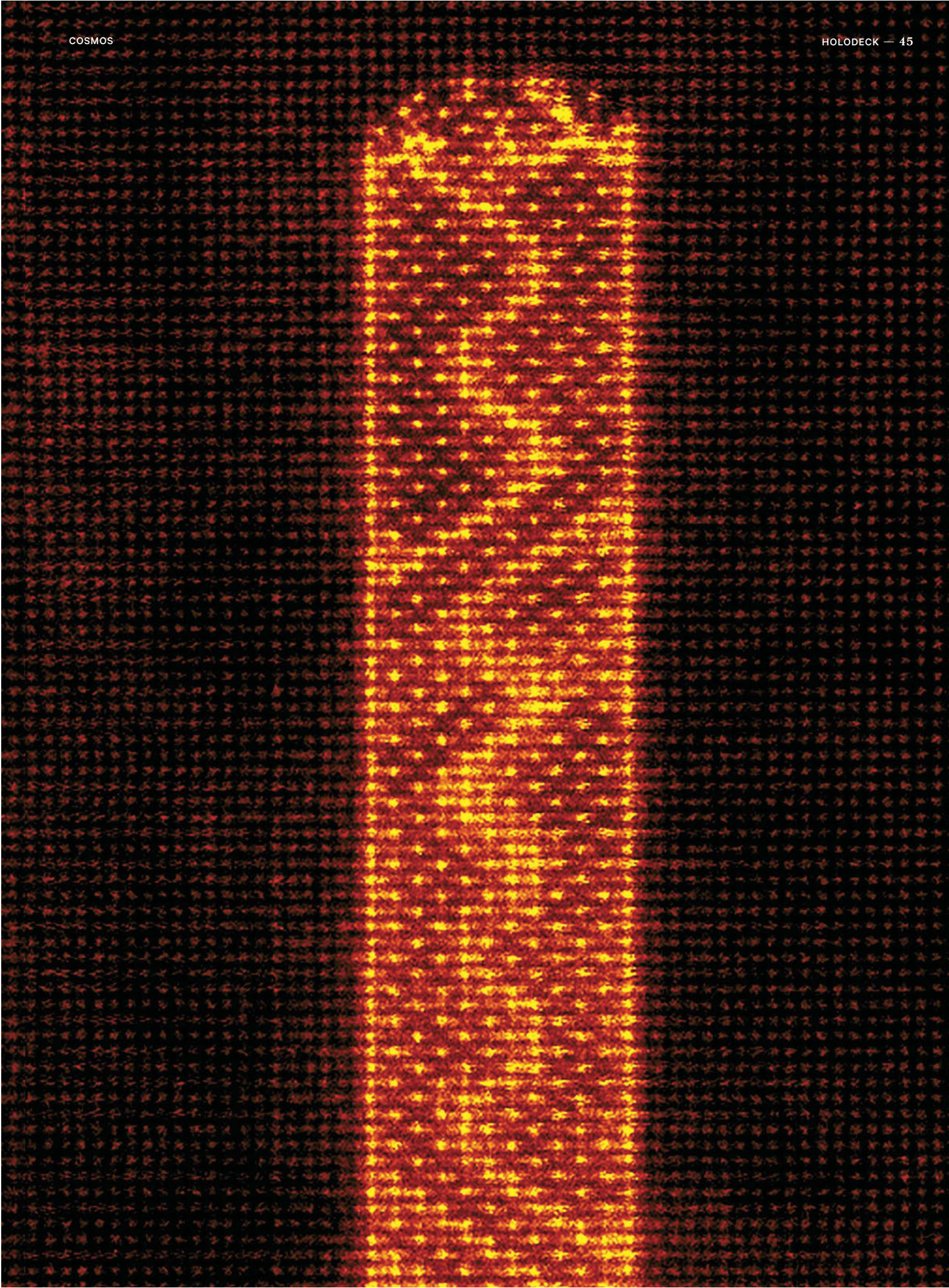
CREDIT: M WEYLAND / Z XU / J F NIE / MONASH CENTRE FOR ELECTRON MICROSCOPY

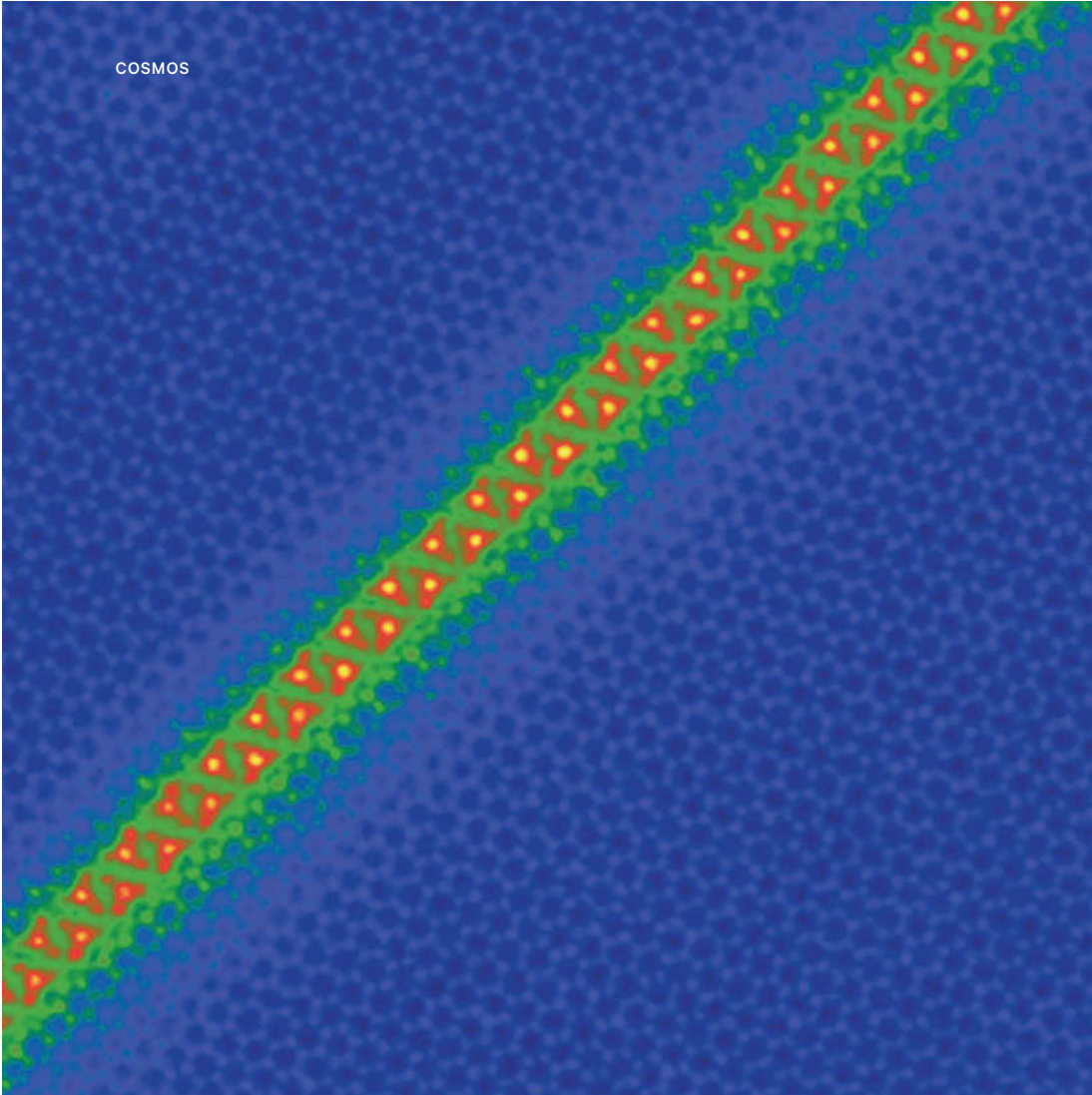


INDUSTRIAL STRENGTH

Pure aluminium is easy to bend – think of kitchen foil. To give this metal the rigidity and strength it needs for buildings, cars, bicycles and planes, you need to mix the aluminium with copper. Once mixed into molten aluminium, it deposits into plates only a few atoms thick (here brightly coloured in yellow). Each cubic millimetre of alloy has thousands of these plates scattered in all directions, reinforcing the aluminium, in the same way steel rods reinforce concrete. When the metal is stressed, the plates act like roadblocks to moving atoms. Here, we see a section of aluminium alloy revealing one of these plates. The zigzags of brighter spots form where more copper atoms have stacked on top of each other.

CREDIT: S WENNER / NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

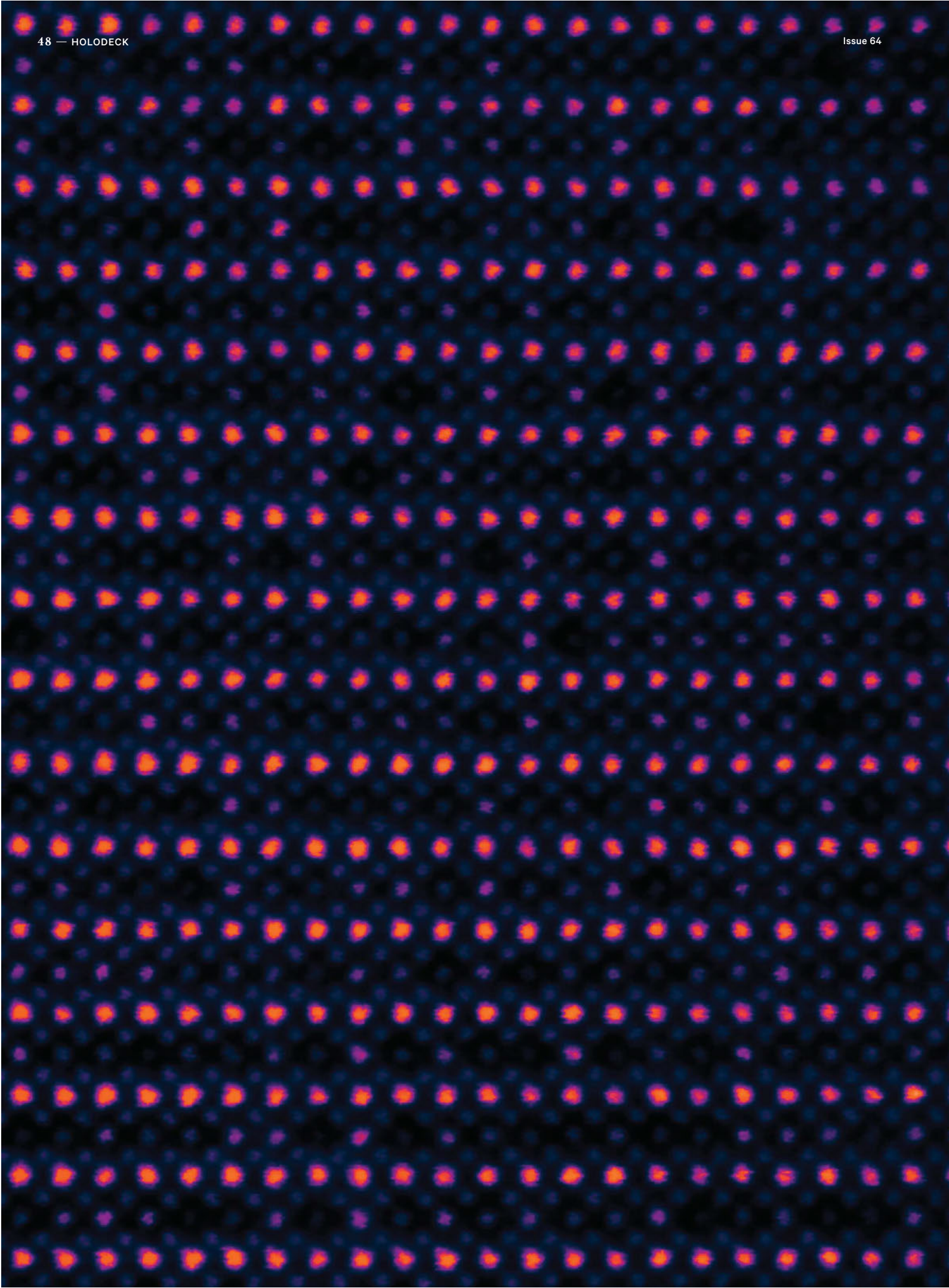




STREAMLINERS

Aerospace engineers want ultra-strong, light-weight materials to build planes. Magnesium is light and its alloys are top candidates. But can they be stronger? Yes, by spiking magnesium with 1% of calcium and indium by weight. When added to molten metal, calcium and indium form wafer-thin plates throughout the magnesium, strengthening it. Here we see a cross-section of one such plate. Despite being a mere four atoms wide, they increase the strength of magnesium 10-fold.

CREDIT: Y M ZHU / M WEYLAND / N V MEDHEKAR / C DWYER / C L MENDIS / K HONO / J F NIE / MONASH CENTRE FOR ELECTRON MICROSCOPY



TRAPPING HEAT

Think of the hot gases pouring from your car's exhaust pipe: burning fossil fuels waste a lot of energy as heat. Researchers are designing 'thermoelectric' materials that can turn this heat into electricity. The more heat the material traps, the bigger the temperature difference between hot and cold components in a thermoelectric device and the higher the voltage it can generate. This image is of a neodymium-titanium oxide thermoelectric material and was used to study a region thought to act as a heat barrier within it. Understanding the arrangement of atoms will help researchers improve the material's performance. Quentin Ramasse, scientific director of the UK SuperSTEM Laboratory, says: "These images are beautiful but also extremely meaningful." ©

CREDIT: D M KEPAPTSOGLOU / F AZOUGH / SUPERSTEM LABORATORY, UK

**“The kids really
get into the
lessons.
They work
the whole time
and you could
hear a pin drop.”**

– Damian, science teacher





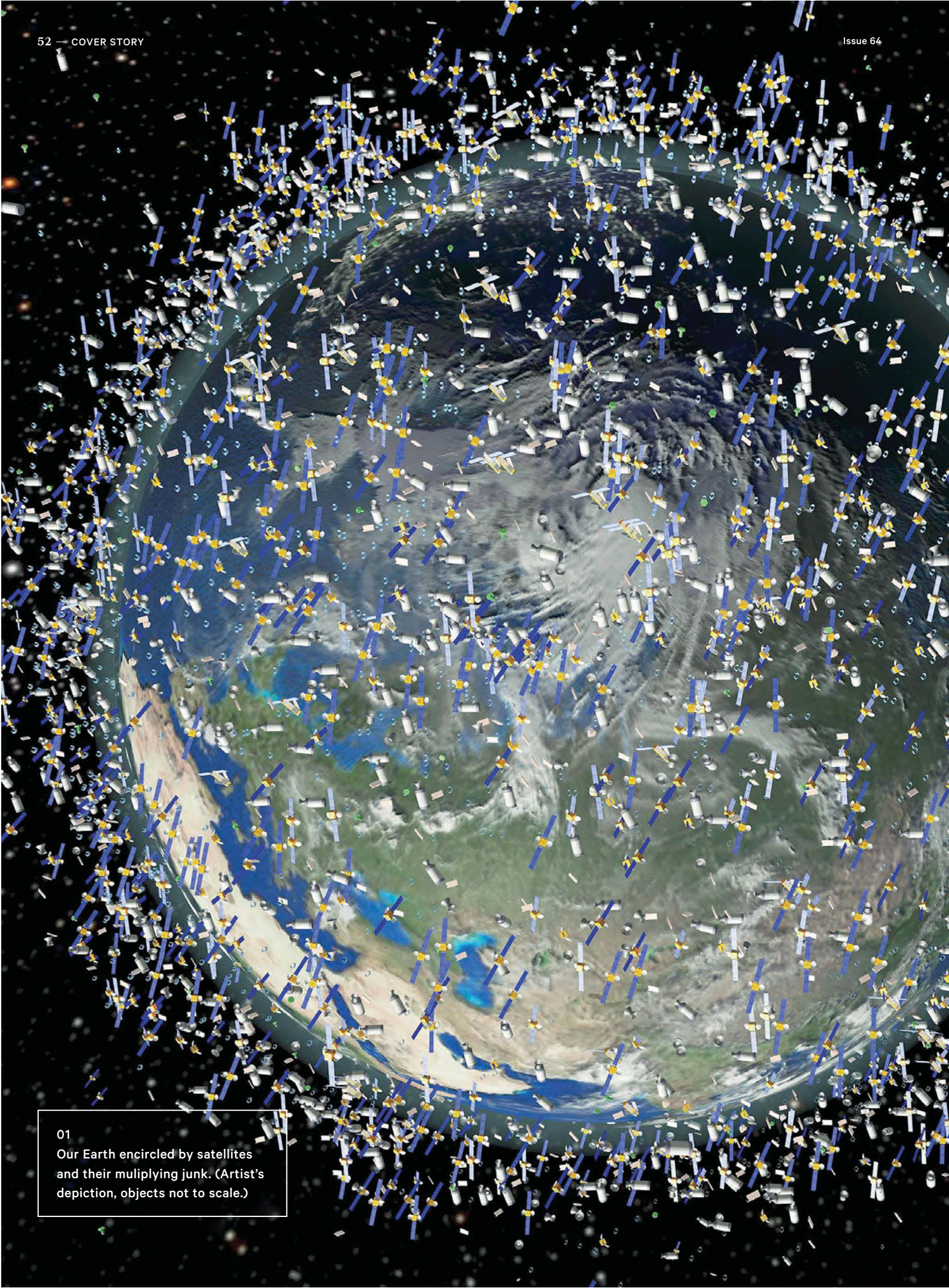
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01
Our Earth encircled by satellites
and their multiplying junk. (Artist's
depiction, objects not to scale.)

OUT OF SPACE

More and more junk is cluttering space, threatening our satellites and rockets.
DANIEL CLERY reports.

OUT IN THE BLACKNESS OF SPACE two astronauts are repairing the Hubble telescope and enjoying glimpses of their blue planet in the distance. At the same time, Russia decides to test an anti-satellite missile. Within minutes, the debris shower takes out the space shuttle and damages the International and Chinese space stations. Will the astronauts survive?

NO ONE YET
KNOWS HOW
TO SNARE
A PIECE OF
TUMBLING
SPACE
HARDWARE
AND DRAG
IT TOWARDS
RE-ENTRY.

MANY READERS WILL RECOGNISE the plot of the movie *Gravity*. Fewer may know that on 10 February 2009, a real space nightmare came true. A satellite belonging to Iridium Communications relaying data to and from mobile phone users was passing over Siberia's Taymyr Peninsula. At 16.56 GMT Iridium 33 was there; at 16.57 it was not. It had collided with a dead Russian military communications satellite. Weighing one tonne and travelling at a relative speed of 12 kilometres per second, the Kosmos 2251 satellite hit Iridium 33 with three times the kinetic energy of an Airbus A380. Both spacecraft disintegrated, scattering wreckage far and wide.

The loss of one of its 66 satellites was a blow to Iridium, but what caused sleepless nights for satellite operators and space agencies everywhere was the floating debris. The US Space Surveillance Network catalogued more than 2,000 fragments bigger than a grapefruit from the collision and a much greater number of smaller ones. At the speeds required for low-Earth orbit, an object the size of a marble can cripple a satellite or punch a hole in a space station. The Iridium-Kosmos crash did *not* cause the kind of devastation depicted in *Gravity*. But there was a tense moment or two: the International Space Station had to make an evasive manoeuvre to avoid a piece of Iridium-Kosmos debris as did other satellites. Around the globe, space agencies suddenly woke up to the threat posed by the thousands of tonnes of objects – operational and dead – cruising in low orbit.

For Donald Kessler it was a Cassandra moment. He'd been predicting a catastrophe of this kind for more than 30 years. A former head of NASA's orbital debris program, he foresaw that if we

continued to launch satellites and leave their paraphernalia floating in orbit, collisions would be inevitable. Each could produce a debris shower capable of crippling other satellites in a chain reaction – a scenario that came to be known as the Kessler syndrome. If nothing is done our planet could end up ringed with a deadly debris belt spelling the end of the satellite age.

Kessler's warnings convinced space agencies to take measures such as directing defunct satellites and used upper stage rockets to re-enter the atmosphere and burn up. But this could be too little too late. Kessler and others believe that the Iridium-Kosmos collision signals that we have entered a new and more dangerous phase. A collision of this scale will likely happen more than once per decade – a *Gravity* scenario playing out in slow motion. If we are to avoid the Kessler syndrome there is only one solution: to hunt down the largest pieces of space junk and remove them from orbit at a rate of at least five objects per year for the next 100 years.

The problem is that no one yet knows how to snare a nine-tonne piece of tumbling space hardware and drag it towards re-entry. And the estimated cost of removing such objects is astronomical. Space agencies can be forgiven for not rushing to start the costly and unglamorous job of sweeping up our orbital back yard.

For Kessler and others, the space junk problem is akin to that of climate change. We're dumping junk and storing up problems for the future; but scientists can't say with absolute certainty that the dire warnings will come true.

So what do you do? Pay a fortune to tackle a problem that may or may not emerge, or do nothing and hope for the best?



02

An artist's impression of the Kosmos 2251 and Iridium 33 collision, the result of too many objects in low-Earth orbit.

BACK IN THE 1960s when Kessler started working for NASA, the big safety concern was space rocks — tiny micrometeoroids weighing less than a gram that drift through the Solar System. He tracked them using telescopes and radar; studied samples collected from the stratosphere by high-flying aircraft; and scrutinised returned spacecraft for the damage they caused.

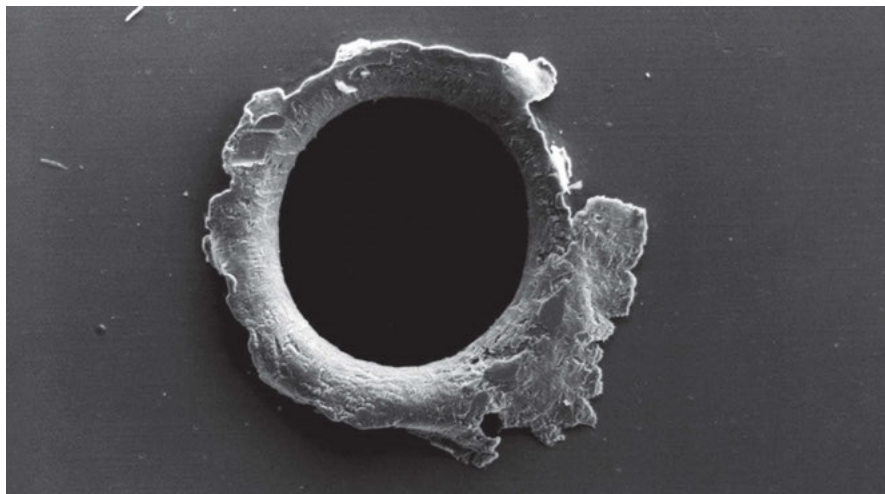
One discovery surprised him. Some of the damage to spacecraft had not been caused by micrometeoroids: it was the work of tiny man-made objects. Even a fleck of paint drifting through space could create havoc.

They simulated what could happen in the lab, firing a hypervelocity gun at unused satellites to develop an impact model, for instance. Kessler's back of the envelope calculations came up with similar results.

"He was very good at that sort of thing," recalls Darren McKnight, a former NASA colleague of Kessler's, now with Integrity Applications Inc.

Bit by bit, evidence mounted about the scale of the problem. In 1981 a Soviet military satellite quietly disintegrated a month after launch, presumably because of a collision. In 1983, a space shuttle came home with a millimetre-wide pit

03



A piece of space debris left this hole in a panel of Solar Max, a satellite launched in 1980 to analyse solar flares.

Kessler turned his attention to the debris problem and in 1978, he published a prophetic paper. A crowded low-Earth orbit would risk cascading collisions; the tipping point would come around the year 2000. "That set the stage for everything that's happening today," Kessler reflected.

But back in the 1970s, the threat wasn't obvious. Kessler says he had trouble convincing authorities of the risks. "The Air Force didn't believe it. They fought it for years."

Ultimately, NASA listened. In 1979 they set up the orbital debris program with Kessler as its head. Its first goal: to calculate the size of the problem and ways to avoid making it worse. The US military's North American Aerospace Defense Command (NORAD) already kept a catalogue of all objects in Earth orbit larger than 10 centimetres.

NASA's debris program began tracking smaller objects with short-wavelength radar.

in one of its windows caused by a high-speed fleck of paint. "It was a slow process. Each new event added one more layer to the credibility," Kessler says.

ONE OF KESSLER'S EARLY DISCOVERIES was that much of the existing debris came not from satellites but from multi-stage rockets. When the bottom stage of a rocket uses up its fuel, it drops back to Earth and the next stage kicks in. The upper stage positions the spacecraft into its final orbit but once its job is done it is left to drift — often containing unburnt fuel that sometimes explodes.

NASA began making sure fuel was vented after upper stages had delivered their payloads and began steering them back towards re-entry where possible. Space agencies in Europe, Russia, Japan and China followed suit.

Defunct satellites posed another problem. In 2002 space agencies agreed to abide by a "25-year rule". Satellite operators would have

to ensure that upper stage rockets and retired satellites re-enter the atmosphere within 25 years.

Saving some fuel for a final downward burn or deploying a sail to increase drag would do the trick.

These fixes seemed to work. The growth in the number of trackable pieces of space debris slowed. The collapse of the Soviet Union in 1991 slashed the number of launches through the 1990s.

At the same time, the Sun was unusually active which heated the outer atmosphere, causing it to swell and increase the drag on debris in low orbits so that more re-entered the atmosphere. For a time it looked as though Kessler's dire forecast would not come true.

Then on 11 January, 2007, in an event that could have inspired the movie, China carried out an anti-satellite test, firing a missile at its own Fengyun 1C weather satellite. The impact created around 3,000 pieces of trackable debris plus an estimated 150,000 pieces larger than a thumbnail – the most junk generated by a single event in the history of spaceflight.

That debris has the potential to do the sort of damage seen in *Gravity*, but in real life things happen much more slowly – space is, after all, a very big place. The anti-satellite test didn't cause any immediate damage but the new swarm of debris made tracking and avoiding objects that much harder.

Then, two years later, came the Iridium-Kosmos crash.

"After those two events, the number of collision avoidance manoeuvres [by operational satellites] increased significantly," says Jer Chyi Liou, chief scientist of NASA's orbital debris program.

Something had to be done. The world's top 13 space agencies asked the Inter-Agency Space Debris Coordination Committee (IADC) to investigate the future stability of the space environment. Six of the agencies – European, Indian, Italian, Japanese, British and American – had developed computer simulations of low-Earth orbit and they all put the same data into their models and made predictions, so that they could form a consensus view.

The six models agreed that the 25-year rule would not be sufficient to stop the increase in space debris. Even if 90% of launches complied with mitigation guidelines, the models predicted debris to grow by 30% over the next 200 years, mostly fed by collisions that would happen roughly every five to nine years.

Most of the mass of space debris still resides in large intact objects, so Kessler and others believe the best policy is to identify the largest objects

in the most crowded orbits and take them down at a rate of five per year for 100 years. "We need to put together a master plan, to change our operations to achieve a sustainable environment.

"The longer we put it off, the more expensive it will be," Kessler says.

AS YET, NO ONE KNOWS the best way to capture errant satellites and stages and put them out of harm's way. Many proposals have been made but none have yet been tested in space. The cost of launching satellites is pretty steep already; the cost of finding dead ones and disposing of them safely could potentially be even steeper, especially if each retrieval mission can only take out a single object. As a result, space agencies are treading carefully, doing studies and experiments on the ground.

The technical challenges are many. Very few dead satellites and upper stages have fittings designed for retrieval operations, so the procedure will require equipment such as a grappling claw, a net or a harpoon. Junk spacecraft may also be spinning, adding further complications. "As of today, there is no economically viable or technically feasible method to allow us to do it," says Liou.

Starting in 2009, the US military's Defense Advanced Research Projects Agency (DARPA) invited aerospace companies to send in their concepts and held an international conference to sound out other ideas. DARPA's report, known as the Catcher's Mitt study, concluded that small debris (less than 5 millimetres across) could be dealt with by building shields around rockets and satellites and that large pieces (more than 10 centimetres) could be tracked and avoided. The analysis concluded the greatest threat to spacecraft comes from medium-sized debris, between five millimetres and 10 centimetres across. Because there is so much debris of that size and it is so spread out, the study could find no practical method of removing it. "The only feasible approach is to go after big things before they break into small things," says Wade Pulliam who led the study for DARPA and is now with Logos Technologies.

Catcher's Mitt advocated taking down between five and 10 large pieces of debris per year to stabilise the amount of medium-sized debris in orbit. It also examined the pros and cons of various removal technologies [see box p61]. But partly because the cost is so huge, Pulliam says we shouldn't rush to get started.

EVEN
A FLECK
OF PAINT
DRIFTING
THROUGH
SPACE COULD
CREATE
HAVOC.

A
CLOSER
LOOK

SPACE JUNK

NUMBER OF MANMADE OBJECTS IN SPACE

4,900
launches
placed some

6,600
satellites in
space of which

3,600
remain intact
in orbit
and about

1,000
are still
operational

100 MILLION +
Manmade objects
bigger than 1 mm

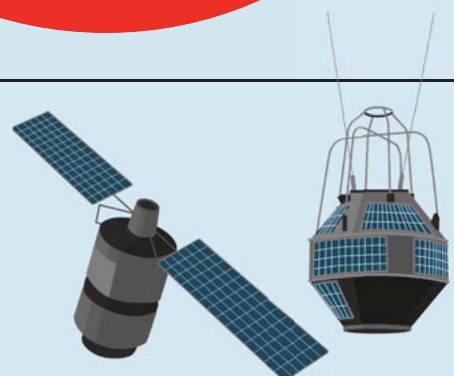
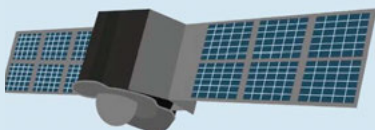
500,000
Manmade objects
bigger than 1 cm

23,000
Manmade objects
bigger than 10 cm

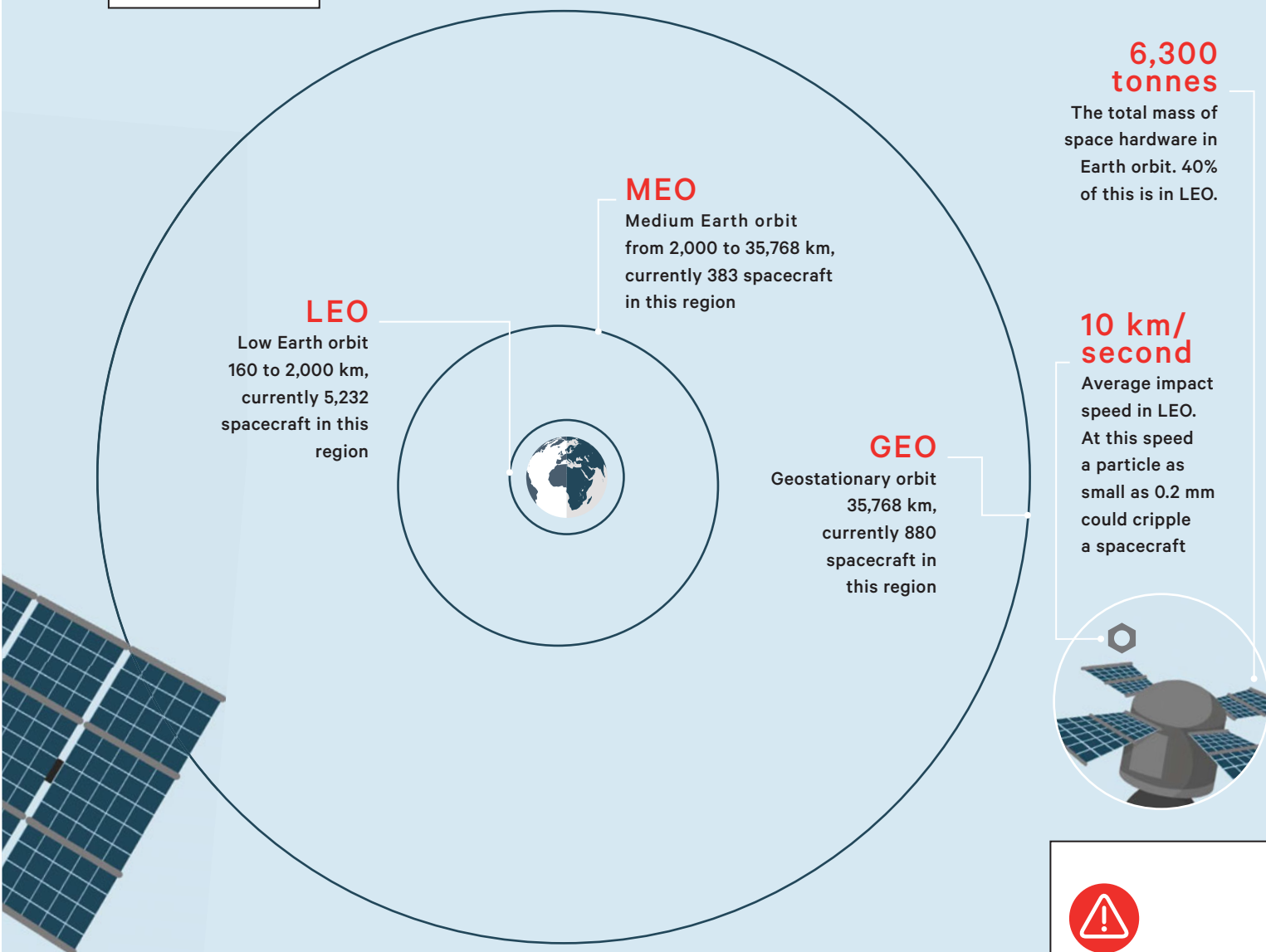
Without satellites orbiting the Earth we wouldn't have GPS or reliable weather forecasts. But a single satellite can disintegrate into millions of pieces. These fragments whiz around so fast that a tiny piece can destroy another satellite.

CRACKING UP IN SPACE

JANUARY 2007:
China blew up its Fengyun 1C satellite in a missile test, creating more than 3,000 pieces of trackable space junk.

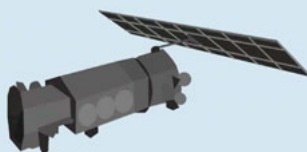


WHERE OUR JUNK IS



FEBRUARY 2009:

The first accidental collision, between Iridium 33 and Kosmos 2251. The satellites collided at a relative speed of 11.7 km/second. Both were destroyed. More than 2,200 trackable fragments were generated.



FEBRUARY 2015:

A battery exploded on a US Defense meteorological satellite. 67 pieces of debris from this event were catalogued in March.



“The greatest risk to space missions comes from non-trackable debris.”

— NICHOLAS JOHNSON, NASA chief scientist for orbital debris.

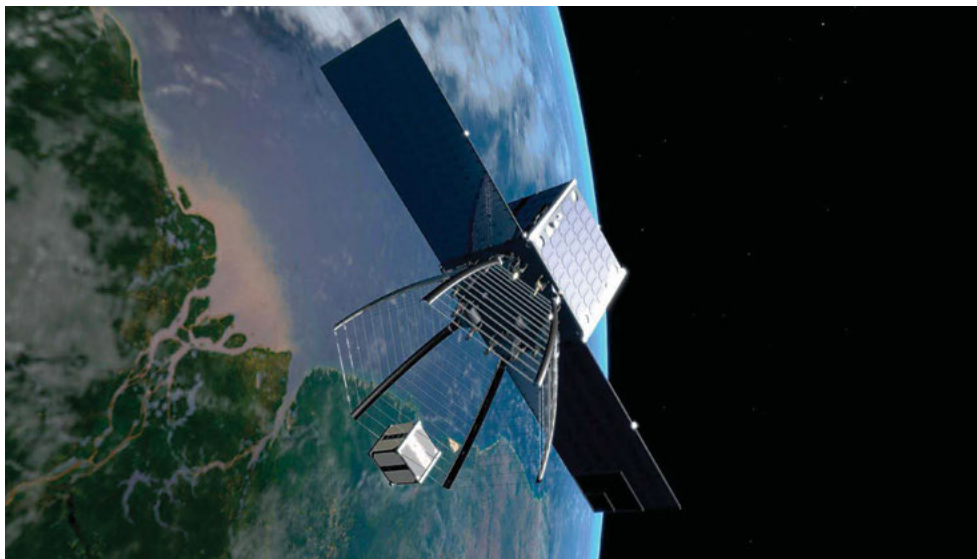
REMOVING
ANOTHER
COUNTRY'S
SATELLITE,
EVEN IF
IT'S DEAD,
COULD BE
SEEN AS A
HOSTILE ACT.

"We have to start thinking about developing the technology but then we should leave it on the shelf. It's not worth deploying it now."

NASA agrees. "The sky is not falling, at least not in the foreseeable future," says Liou. "We do have time to develop the technology ... We don't need to go out and remove debris in the next five years or so — 10 or 20 years, maybe."

But there are signs of progress. Researchers in Switzerland are planning to launch a small retrieval demonstration in 2018 called CleanSpace One. A net will capture a Swiss nanosatellite and drag it towards re-entry. The European Space Agency (ESA) is also drawing up plans. Its researchers have been testing claws, nets and harpoons on the ground. "Each has pros

04



An artist's impression of CleanSpace One, a Swiss spacecraft that will use a net to drag a nanosatellite towards re-entry.

Kessler is concerned about the consequences of delaying until 2035. The 2009 IADC report proposed starting debris removal in 2020 but, he says, we're no closer to doing that today than we were then. "It's urgent to at least put together a plan for how to do this," he says.

"Money is the crux of the problem," says aerospace engineer Hugh Lewis of the University of Southampton in the UK. The issue has gone off the boil since no further collisions have taken place since the Fengyun and Iridium-Kosmos crashes. "The cheapest thing is to do nothing," Lewis says. But this is not an option, he adds. "We should get ready, understand the probabilities, and be ready to go if we need to."

There are also thorny legal issues. According to international space law, responsibility for satellites in orbit rests with the country that launched them. Removing another country's satellite, even if it's dead, could be seen as a hostile act. Some might even view a system to remove satellites from orbit — especially one based on ground-based lasers [see box] — as a weapon.

and cons ... there is no perfect solution," says Luisa Innocenti, head of ESA's CleanSpace office. The exact technology they will use is still taking shape, but Innocenti and her team are aiming to propose a mission costing several hundred million dollars and launching around 2021 to the ESA council when it next meets to decide budgets in 2016. Innocenti says this first mission will be ambitious, but the ESA has a good track record. "We have landed on a comet. I do not doubt that we will get there," she says. "If we at least prove it can be done, it will be a message." ©

DANIEL CLERY is a news editor with *Science* magazine and the author of *A Piece of the Sun: the Quest for Fusion Energy*.

IMAGES

01 Science Photo Library / Getty Images
02 Stefan Morrell / National Geographic
03 NASA
04 EPFL / Jamani Caillet

A
CLOSER
LOOK

HOW TO CLEAN UP SPACE JUNK

IN 2009, THE CATCHER'S MITT STUDY from the US Defense Advanced Research Projects Agency (DARPA) examined proposed technologies for cleaning up space junk.

The study started with the premise that medium-sized space debris (between 5 millimetres and 10 centimetres across) is the biggest threat to spacecraft because it is too large to be shielded against but too small to be tracked and avoided.

The study estimated that around 20,000 new pieces of medium-sized debris are created per year, so regular removal would be needed.

Industry, space agencies and academic scientists put forward their plans for analysis by DARPA. The study's conclusions are shown in bold below.

A number of the proposed solutions involved as yet untested technologies for launching spacecraft that don't require fuel to chase debris, including solar-powered ion thrusters. This is because of the high cost of launching a spaceship with a heavy cargo of fuel.

There are also several other ways a device designed to capture space junk could do its job:

1 – Drag Enhancement. Attaching a large sail or balloon to the debris so that atmospheric drag pulls it to re-entry. This method only works in lower orbits.

2 – Solar Sail. Attaching a thin reflective sail which uses radiation pressure from sunlight to carry the debris out of orbit.

3 – Electromagnetic tether. Attaching

a conducting cable several kilometres long to the object. By interacting with the Earth's magnetic field, the tether will slow the object and take it out of orbit.

But a danger is that the tether could be cut by debris or become tangled if the object is spinning.

4 – Slingshot. A catching device fitted with a claw/net/harpoon captures the junk during a high-speed pass.

The connected device and debris spin around each other at the opposite ends of a tether. Releasing the debris at the right moment – a move like an Olympic hammer-thrower's – will send the debris hurtling towards re-entry.

A high degree of accuracy and predictive modelling is needed for this to work. ☹

THE DARPA STUDY



SWEEPERS —

Numerous designs for orbit-cleaning 'sweepers' were proposed, which would absorb or simply slow down pieces of debris. Capture materials included multilayer foils, aerogel panels and layered open-cell foam. Passive sweepers cruise around debris-filled orbits catching whatever comes their way. Active sweepers identify debris and steer into its path.

Conclusion: Because debris is so widely scattered, sweepers would need to be vast in extent and launched in huge numbers, incurring enormous launch costs. Active sweepers would need large fuel supplies for frequent manoeuvres. High risk of collision with satellites or large debris. Currently impractical.



LASERS —

Firing a laser at debris causes some of its material to boil off at high speed, causing a thrust in the opposite direction. This can slow pieces of debris so they descend towards re-entry. Lasers could be launched into space or built on the ground and fired up through the atmosphere.

Conclusion: Debris is of irregular shape and possibly tumbling, so ensuring the thrust acts in the right direction is difficult. Powerful enough lasers do not yet exist and firing through the atmosphere bends the beam. Tracking is not yet accurate enough. Any laser system capable of downing debris would be seen as an offensive weapon by many countries. Currently impractical.



LARGE DEBRIS REMOVAL —

If removal of medium-sized debris is impractical then all we can do is remove dead satellites and rocket components to stop them becoming future debris. Any clean-up system would likely consist of a mothership that deploys devices capable of taking down a single object. The mothership would need to identify objects and manoeuvre close to them. It would need to grapple the object with a claw, net or harpoon and drag it down.

Conclusion: Identifying, manoeuvring close to and grappling an object are all untested challenges, especially if the object is spinning. But a bigger problem may be fuel. Launching enough chemical propellant for the mothership to chase multiple objects as well as the boosters to bring the objects down would be very costly.

THE UNIVERSE THAT BEGINS AGAIN

The failure so far to find gravitational waves has some cosmologists wondering if the ‘inflationary’ theory of the Big Bang is right. **MICHAEL D. LEMONICK** explains.



IN MARCH 2014, the BICEP2 microwave telescope at the South Pole detected swirls that were mistakenly believed to be the imprint of gravitational waves.



ON 17 MARCH, 2014, the Harvard-Smithsonian Centre for Astrophysics held a press conference to announce “a major discovery”. It was not an exaggeration. A team of astrophysicists had detected evidence of gravitational waves from a time when the Universe was almost indescribably young.

IT WAS THE MOST POWERFUL confirmation yet of the 30-year-old theory of inflation which explains why the cosmos looks the way it does. The distribution of galaxies, the relative proportions of ordinary matter and dark matter, the curvature of space-time, the fact that the cosmos looks essentially the same no matter where you look – all of this can be understood if you assume that the entire visible Universe expanded for the briefest interval from something about the size of a proton to something about the size of a grapefruit at faster than the speed of light when it was less than a billionth of a trillionth of a trillionth of a second old. In the words of University of California, Santa Cruz, cosmologist Joel Primack: “No theory this beautiful has ever been wrong.”

Evidently, it had been proven right. Using an exquisitely sensitive microwave telescope known as BICEP2 located at the South Pole, Harvard’s John Kovac and a team of observers had detected a twist in the orientation of microwaves generated about 300,000 years after the Big Bang. Known as B-mode polarisation, it had been predicted by inflation theory. The fantastic energy released by an inflating Universe would have rippled space-time itself.

Alternative theories about how the Universe got its structure – such as the one developed by Princeton University’s Paul Steinhardt – did not predict these ripples. “If this is correct, we’re finished,” Steinhardt commented. He had been one of the pioneers of inflation theory but had since abandoned it in favour of his own competing theory.

The announcement at the Harvard press conference reverberated in headlines around the world. “Space Ripples Reveal Big Bang’s Smoking Gun,” trumpeted the *New York Times*. “Primordial gravitational wave discovery heralds ‘whole new era’ in physics,” declared the *Guardian*.

Like virtually every other story that appeared on that day, there were dutiful caveats along the lines of “The results will require confirmation...” They barely dented the feverish tone.

Within days of the announcement the reporters were wishing they’d been more than merely dutiful. Kovac’s scientific report (revealed online on arXiv – a forum for work to be published soon) wasn’t released until the press conference. Once other astrophysicists got a look at it, they became suspicious. Primordial gravitational waves aren’t the only thing that could polarise microwaves. The Milky Way’s swirling dust clouds could do it too – “schmutz”, Princeton’s David Spergel called it, using a Yiddish word meaning “dirt.”

As independent physicists scrutinised the report more closely, they became increasingly sceptical as to whether the Harvard team had seen gravitational waves at all. Finally in February 2015, a combined analysis of the data from Kovac’s BICEP2 team; the Keck Array (located next to BICEP2 at the South Pole); and Planck, the European Space Agency’s orbiting space observatory, left the researchers in no doubt. “What we see”, Kovac conceded “is compatible with no inflationary gravitational waves”.

THAT HARDLY MEANS that inflation is dead. What these three very sensitive instruments saw is also compatible *with* inflationary gravitational waves hiding within the dust. Inflation, moreover, isn’t a single theory: it’s a class of theories, and many predict gravitational waves 10 orders of magnitude lower than any existing instrument is capable of detecting. “Am I worried?” asks Stanford University theorist Andrei Linde, one of the founders of inflation theory. “Why should I be?”

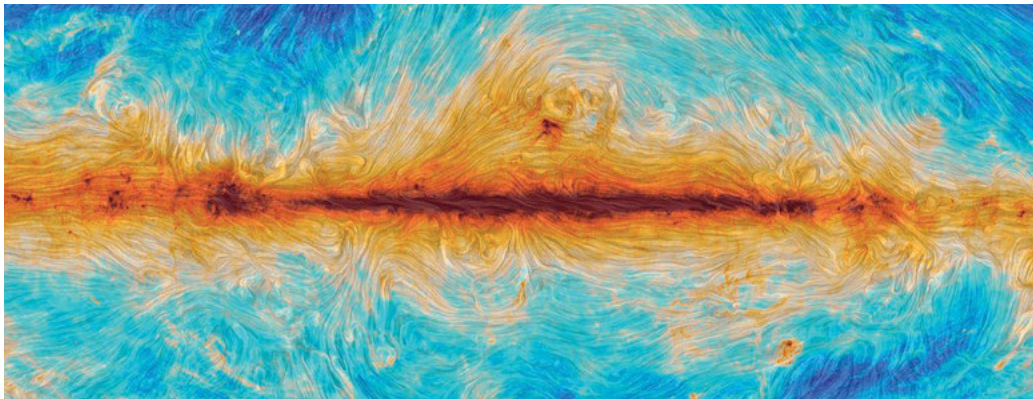
But for a small number of theoretical

astrophysicists, the failure to detect gravitational waves raises the stock for an alternative theory of the birth of the Universe. Known as the cyclic model, it was first proposed in 2003 by Princeton's Steinhardt and Neil Turok, then at the University of Cambridge (now director of Canada's Perimeter Institute for Theoretical Physics). These days it is championed by a handful of theorists mostly in the US and the UK. It posits that the observable Universe has gone through alternating phases of expansion and contraction — perhaps forever. This model of cosmology explains everything we know about the Universe just as well as inflation does, they say. A major point of departure though, is that primordial gravitational waves are *not* part of the cyclical model.

the 1964 discovery of the cosmic microwave background (CMB) radiation. At the time, there were two competing theories about how the Universe began. One was the Steady State, which posited that the Universe has always been expanding, and that new matter is created to fill in the gaps as existing matter spreads apart.

The other was the Big Bang, ironically coined by English astronomer Sir Fred Hoyle as a term of ridicule — he was the leading proponent of the Steady State. The original idea here was that the Universe was born out of the violent expansion of an extremely dense, hot gas cloud (a modern version holds that it began from a singularity — a pinpoint of sub-atomic proportions) which has been expanding ever since. If that were true, then the brilliant light

02



The swirls detected in this picture of the Milky Way were initially believed to be caused by gravitational waves, but later measurements showed cosmic dust could create the same effect.

While most physicists are not even close to abandoning inflation, they don't rule out that this beautiful theory may also be wrong. "Paul has a bunch of concerns about the inflation theory, which I think are valid," says Charles Bennett, an experimental physicist at Johns Hopkins University.

Joanna Dunkley, a cosmologist at the University of Cambridge, agrees the failure to detect gravitational waves "should make us think more seriously about whether inflation is the only option".

"I think most of the community is focused on inflationary models, and I think some of that is fashion," adds David Spergel, Steinhardt's Princeton colleague.

Fashion explains some of their focus, perhaps, but hardly all of it. When inflation theory first emerged in the 1980s, it was nothing short of breathtaking in the way it explained a series of problems that had bedeviled cosmologists since

generated by that bang should still be echoing through the Universe — except the expansion of the Universe would have stretched the light into the microwave region of the electromagnetic spectrum.

In 1964, radio astronomers Arno Penzias and Robert Wilson at the Bell Telephone Laboratories in New Jersey, stumbled across that stretched ancient light. They were experimenting with Bell Lab's giant radio antenna — originally built to track satellites — to see if they could repurpose it to peer at the Universe. Annoyingly, their efforts were thwarted by a mysterious microwave frequency hiss in the antenna. When the meticulous pair had ruled out all other explanations (including pigeon poop) they suggested the hiss was cosmic in origin. Around the same time, just an hour's drive to the west, Robert Dicke and several other physicists at Princeton University were setting out to look for relic microwaves from the Big Bang. Penzias and Wilson heard about Dicke's project and called during one of his group meetings. As those who

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THE INFLATION MODEL IS “HORRIBLY FINE-TUNED”.

were present recall, Dicke listened patiently, hung up and said “boys, we’ve been scooped”.

Both groups published simultaneously in *The Astrophysical Journal* in 1965 (only Penzias and Wilson got the Nobel, however). The discovery tipped the scales firmly in favour of the Big Bang.

Cosmologists leapt at the opportunity to study the CMB in detail – it was the first glimpse of our youthful, 400,000-year-old Universe. It turned out to be a mysterious place. For one thing, they were struck by its uncannily uniform temperature – it hovers at 2.725° above absolute zero, varying by no more than one part in 100,000 in either direction, no matter where in the sky you look. The turbulent super-heated gas cloud from which the Universe erupted would have had spots that varied significantly in temperature and density and some of that messiness should have been on show in the structure of the early expanded Universe.

Another problem was that while the strapping 400,000-year-old Universe was as smooth and even as a baby’s bottom, the mature universe is wrinkled with features such as galaxies. But how did these age-related wrinkles arise?

Physicists were also worried by the apparent topology of the early Universe. Over large scales, their measurements showed that it appeared to be geometrically “flat” [see box]. And it was unclear why monopoles – particles with either a north or south magnetic charge but not both – had never been found.

Cosmologists scratched their heads for more than a decade. Then in 1980 a young physicist named Alan Guth figured out these conundrums would vanish if a proton-sized Universe experienced an ultra-fast expansion in its very earliest moments.

A proton-sized beginning that suddenly inflated would explain the evenness of the Universe. It would have ballooned out so fast there was no time for any fluctuations to wrinkle the expanding fabric of space-time.

On the other hand, the fact that the entire Universe was once sub-atomic in size made it subject to quantum effects such as “uncertainty” – a state in which physical variables can fluctuate unpredictably. These random quantum fluctuations seeded the wrinkles that gave rise to features such as galaxies.

Finally, inflation explained why the visible cosmos appears so flat. Perhaps it started off with significant curvature like the surface of a balloon. Imagine that you’re a fly balancing on the ball. Suddenly, it expands to the size of the Sun.

You’re still standing on a curved surface, but to you it now looks utterly flat as far as the eye can see. Without the rapid expansion, the balloon wouldn’t have expanded sufficiently to create the flatness we observe.

Guth’s original version of inflation left some gaps but they were filled by Linde, turning the theory into a robust set of predictions that cosmologists have been testing ever since.

THERE WAS A PROBLEM, HOWEVER.

“We discovered early on that we completely misunderstood something at the beginning,” says Steinhardt, who was one of the pioneers of inflation theory. “We thought that inflation was essentially a story about stretching the Universe. And then we thought if you add a little bit of quantum mechanics to explain why the Universe isn’t perfectly uniform” – why it has galaxies and clusters of galaxies – “we seem to have a consistent story”.

However, there’s no such thing as *a little bit* of quantum mechanics, says Steinhardt. “Quantum physics is constantly producing fluctuations in all forms of energy, including the energy that’s driving inflation, so that it ends in some places a little bit later than others,” he says.

He and others soon realised that quantum uncertainty complicated matters.

In our patch of the Universe, for instance, inflation stopped billions of years ago, but in some other patches it’s still going on. Given inflation’s breakneck expansion rate, these regions would now be unimaginably large – as though bits of the original balloon had bulged outward to form gigantic protuberances, much larger than the original. “This will occur over and over and over again,” Steinhardt explains. Linde, who is mostly responsible for this idea, calls it “chaotic inflation” or “eternal inflation”. It means that our own visible Universe is just one patch in a far larger multiverse – a patch within a patch within a patch, ad infinitum – and each patch could have its own unique laws of physics. “The multiverse will explore every conceivable physical property and possibility and produce every conceivable outcome,” says Steinhardt.

And that’s the problem. “What can you predict from such a theory?” Steinhardt asks. “Nothing. Literally nothing, since anything that’s physically possible will occur.” But it’s worse than that: since an infinite number of patches exist with an infinite variety of physical laws and constants, the fundamental question that physicists have been trying to answer since the time of Aristotle

— why is the Universe the way it is? — becomes meaningless. It's the way it is because the Universe is every possible way all at once. Ours happens to look the way it does because that's the part we happen to be living in. This is what's known as the anthropic principle, and since it says in essence that there's no explanation for anything, it pulls the rug out from under science. That doesn't make it wrong, but physicists tend to abhor it.

03



Insurgents Neil Turok, above, and Paul Steinhardt, below, argue for a cyclic model of the Universe.

There's a second problem as well. "It's remarkable that we have a theory that can describe what's going on and match the observations so beautifully," says Spergel. "But it doesn't explain how it got into that phase." In other words inflation might have happened but nobody knows why it started. Inflationary theorists say that's a problem to be solved later, says Steinhardt. "But it's a big problem to be solved later," he says, "because we've been trying to solve that problem and we think the conditions under which inflation could begin are very, very rare." Unless you believe in a Creator, that's not a good place to be.

There was a third problem: dark energy. In 1999 cosmologists confirmed that this mysterious force is ballooning out the Universe at an ever-accelerating rate. Inflation theory, conceived in the 1980s, was blissfully unaware of dark energy.

"It was a total surprise," says the Perimeter Institute's Turok. "Inflation was already something of an artificial add-on to the Big Bang, and now you've got this new add-on, which has nothing to do with inflation." Turok says you also have to account for the fact that inflation dominated the earliest moments of our part of the Universe, then went away — and that dark energy (tiny compared

with the energy of inflation) would emerge billions of years later to dominate the Universe.

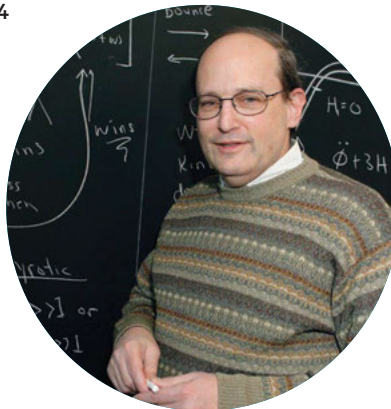
Inflationists consider dark energy to be something entirely different from inflation — a second expansionary force that only became significant many billions of years after inflation ran out of steam. The fact that you need to explain not one, but two different forces makes Steinhardt and Turok uncomfortable with the inflation model. "It's horribly fine-tuned," says Turok.

For this pair of physicists, dark energy had finally robbed inflationary theory of its beautiful shine. There had to be a simpler, better theory. After several years of intensive work, they came up with the cyclic model.

In the cyclic model, dark energy doesn't suddenly turn off after the creation of the Universe and then return. Instead, it is dark energy — which we can observe as opposed to inflation which is theoretical — that drives the initial expansion of the Universe and continues the process, strengthening as the Universe ages.

Ultimately it also reverses direction, a possibility that other theorists had considered even before the cyclic Universe scenario was proposed. The reversal takes a long time — perhaps as much as 10^{500} years. But eventually the Universe collapses to a tiny size (the model doesn't specify precisely how small, but it's far larger than inflation calls for). Then the dark energy reverses direction again, the Universe begins to expand, and a new cycle bounces into being. "In this model," Turok says, "there is no inflation, and dark energy isn't a bizarre add-on: it's essential."

04



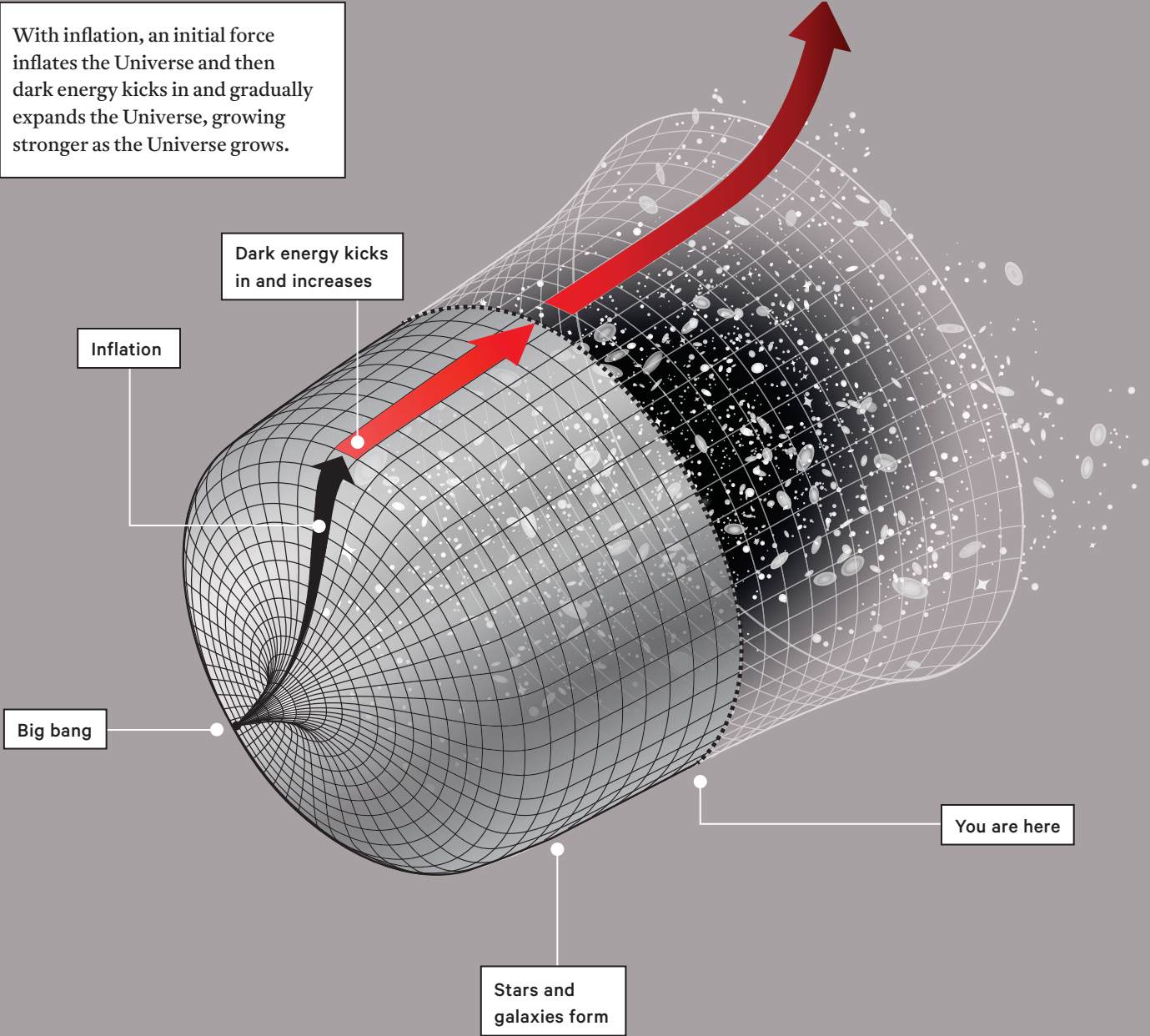
By positing a Universe that expands for many billions of years, then contracts then expands again, perhaps infinitely many times, Steinhardt's and Turok's theory addresses many of the same mysteries inflation appeared to solve.

A
CLOSER
LOOK

THE TWO THEORIES

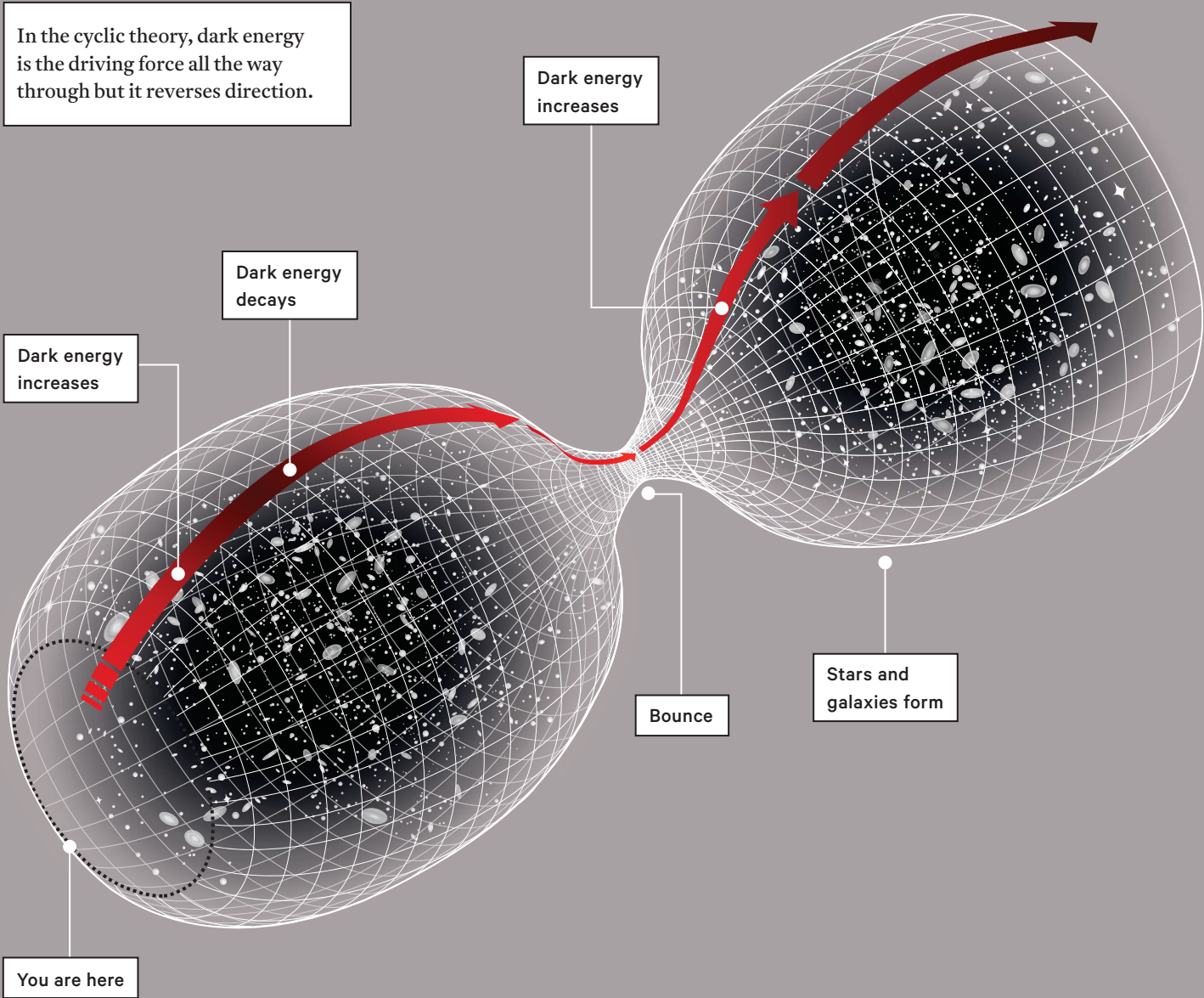
INFLATION THEORY

With inflation, an initial force inflates the Universe and then dark energy kicks in and gradually expands the Universe, growing stronger as the Universe grows.



CYCLIC MODEL

In the cyclic theory, dark energy is the driving force all the way through but it reverses direction.



WHEN THE
AVERAGE
COSMOLOGIST
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THE MORNING,
HE OR SHE
PROBABLY
STILL THINKS
SOMETHING
LIKE
INFLATION
HAPPENED.

For example, because the cosmos has gone through many, many cycles, it has had ample time for different regions to have come into temperature equilibrium, so there's no problem with the fact that opposite sides of the visible Universe look essentially the same. And the topological "flatness" of the visible Universe might emerge not from ultra-fast expansion but from the effect of dark energy during the contraction. Precisely how the reversal happens is something Turok and Steinhardt haven't worked out yet. "There's a lot of effort in the field right now," says Steinhardt, "different approaches for thinking about these bounces, but they all have the feature that they are continuous processes, meaning there can't be anything too crazy that happens as you're going through them" — for example, nothing as crazy as the singularity where density becomes infinite and physics breaks down — a state that appears inevitable if the Universe expands only once.

While both physicists are convinced that the cyclic theory is more straightforward and plausible than the inflationary model, they realise their arguments won't be enough to wean their colleagues away from inflation. Both theories match existing observations very well, and neither Steinhardt nor Turok is prepared to say the cyclic model is clearly better at this point. But there's one observation that could decide between them. Gravitational waves are predicted by inflation; cyclic models say they shouldn't exist.

IF THE BICEP2 TELESCOPE had actually found the signal its scientists claimed last spring, that would have been the end of the road for Steinhardt's ideas. The fact that it didn't, he says, should inspire other physicists and astrophysicists to take another look at cyclic models.

For Steinhardt, cosmology is experiencing a challenge akin to that faced by planetary astronomers of the mid-1500s. Ptolemy's Earth-centred Solar System was the reigning view but contested by Copernicus' Sun-centered theory. "Copernicus could explain some things conceptually that Ptolemy couldn't", says Steinhardt, "and vice versa". It was only when Kepler realised the planets follow elliptical rather than circular paths that Copernicus' model pulled ahead. In Steinhardt's view this is a Kepler moment.

Most physicists aren't quite ready for that. "It's still possible with the BICEP2 and Planck data that there could be a whopping great gravitational wave signature," says Cambridge's Joanna Dunkley. "It's not that BICEP2 has got no signal at all, it's just the signal is much more likely to be dust than the Big Bang."


As observers continue to refine their observations of the dust, however, it will become easier for them to subtract the dust signal electronically and see if there are any truly primordial polarised microwaves hiding behind it — much as they do now when observing vanishingly dim galaxies through the Earth's atmosphere.

And even if no inflation signal emerges out of the dust, the waves could well be out there but beyond the limits of current detectors to find them. "There's a very large spectrum of possibilities for the intensity of those gravity waves," says Guth.

That could change over the next few years, however, as Planck satellite data continues to be analysed and as other ground-based CMB detectors continue their watch for signals from the ancient Universe. They include the balloon-borne SPIDER detector, which just completed a loop around Antarctica; the Atacama Cosmology Telescope, the POLARBEAR experiment and the Cosmology Large Angular Scale Surveyor in Chile; the South Pole Telescope; the Harvard group's Keck Array, and more. All of them are looking for polarised light — some scanning larger patches of sky in less detail, others looking at small patches more intensively. "A lot of people are thinking up new ways to measure this very, very tiny signal," says Lyman Page, Steinhardt's Princeton colleague "and we've been thinking about it for years".

Each instrument will make valuable observations in its own right, says Bill Jones, a Princeton physicist who works with the SPIDER experiment. "It's sort of like a force multiplier in the sense that we can take advantage of the different strengths that they have in order to really nail the signal," he says.

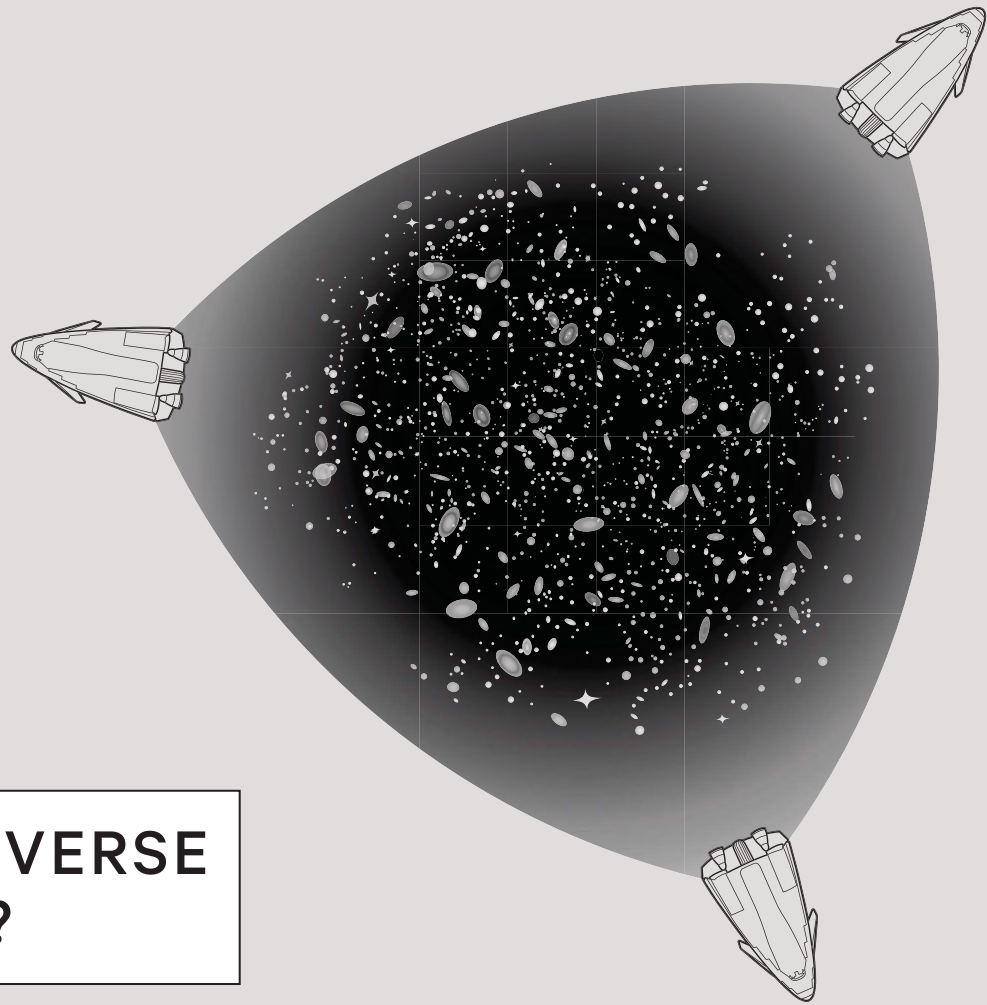
Like most of his colleagues, Jones acknowledges that the cyclic models are interesting — even intriguing. But he adds: "I think that when the average cosmologist wakes up in the morning, he or she probably still thinks something like inflation happened."

Steinhardt, Turok and the other crusaders for the cyclic model are fine with that. For now. 

MICHAEL D. LEMONICK is the senior staff writer at Climate Central and a former senior science writer at *Time* magazine.

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- 01 Keith Vanderlinde
- 02 ESA and the Planck Collaboration
- 03 Peter Power
- 04 Beverly Schaefer
- 05 Anthony Calvert



THE UNIVERSE IS FLAT?

A bear walks 10 kilometres south, then 10 kilometres west, then 10 kilometres north and ends where it started. What colour is the bear?

THIS PUZZLE PLAYS with our expectations that directions on Earth are described with flat geometry (find a city block: walk north 100 metres, east 100 metres, south 100 metres then west 100 metres and you end up back where you started, right?). This predictable behaviour is more or less what flat geometry means.

Near the North Pole, the flat geometry of our conventional direction system does not hold. The angle between the north-south line and the east-west line is *not* perpendicular. In this case, our direction system has a “curved” geometry. That’s how you can figure out the bear is white.

Another example. Go to the beach. Draw a triangle in the sand and all its angles add up to 180° . The beach is flat. Climb a sand-dune and draw the same triangle: its angles will add up to *more* than 180° (the curvature is positive so the triangle bulges).

If you crawl into a little valley between two sand dunes and draw the same triangle again, its angles will add up to less than 180° (the curvature is negative so the triangle puckers).

Let’s fly our triangle into space. Imagine you have three spaceships flying in formation. If they are out in empty space, the angles of their triangle will add up to 180° , as we expect. But that’s not the case everywhere. If the ships fly near a black hole, the curvature of space changes, and their triangle no longer adds up to 180° .

On a local scale, the curvature of space can be positive or negative, like undulating sand dunes on a beach.

In a flat Universe as a whole, averaged over all of space, the curvature is zero. If our three spaceships split up, each flying in a different direction to the furthest edges of the Universe, their Universe-sized triangle would add up to exactly 180° .

How do we know the Universe is flat? By measuring the density of mass in the Universe.

Because gravity curves space, the shape of the Universe is largely determined by

how much mass it contains compared to its size. The critical density for a flat Universe works out at about five atoms of hydrogen per cubic metre, averaged over the entire Universe. If the mass density is above this critical level (say six atoms of hydrogen per cubic metre) then the Universe would have enough gravity to curve like the top of a sand dune. If the density is less (say four atoms of hydrogen per cubic metre) then the Universe would curve the opposite way, like the valley between two sand dunes.

According to our best picture from the cosmic microwave background, the observable Universe is flat to within a 0.4% margin of error. The surprising flatness means the mass density in the Universe is balanced on a knife-edge.

This astronomical coincidence has cosmologists scratching their heads. [see main feature]

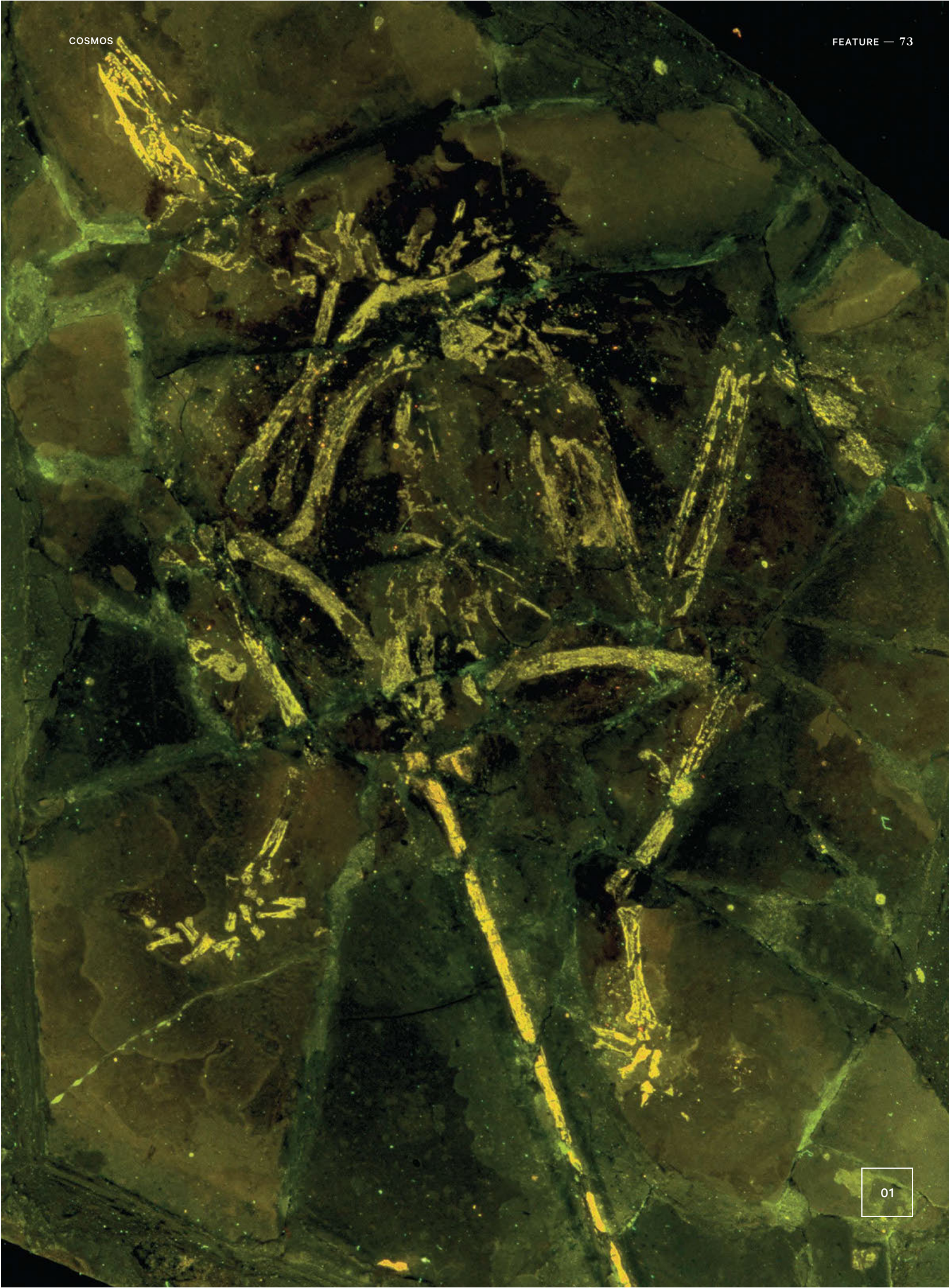
— CATHAL O’CONNELL

THE GREAT FOSSIL HOAX

China has enjoyed an unprecedented gold rush of feathered dinosaur fossils — but how many are real? JOHN PICKRELL reports.



X-RAYS SHOWED this spectacular missing link between bird and dinosaur was a cut-and-paste of different fossils.



NATIONAL GEOGRAPHIC'S SENIOR EDITOR

Christopher Sloan had seen a feathered dinosaur fossil or two. But the specimen he described in the magazine's November 1999 issue, dubbed *Archaeoraptor liaoningensis*, took his breath away.

HIGH-QUALITY
FOSSILS CAN
SELL FOR
TENS OF
THOUSANDS
OF DOLLARS.

"ITS LONG ARMS AND SMALL BODY scream 'bird!' Its long, stiff tail – which under magnification erupts into a series of tiny support rods paralleling the vertebrae – screams 'Dinosaur!'" Sloan wrote. The creature, found in Liaoning Province, China, "is a true missing link in the complex chain that connects dinosaurs to birds".

Archaeoraptor would later be dubbed "Piltdown chicken". Like England's infamous Piltdown man it turned out to be a cut-and-paste fossil made of different species. For *National Geographic*, a bastion of scientific publishing, to have been taken in by the hoax showed the sophistication of the forgery.

THE PROBLEM OF FAKED FOSSILS in China is serious and growing. Rather than being excavated by palaeontologists on fossil digs, most of the region's fossils are pulled from the ground by desperately poor farmers and then sold on to dealers and museums.

Liaoning, an impoverished and heavily industrialised province of north-eastern China, has been a centre for paleontological activity since the early 1990s. When *Sinosauropteryx* – the first known feathered dinosaur – was discovered there in 1996, it spurred a fossil-hunting gold rush the likes of which had never been seen before.

Cretaceous-era Liaoning was rich with lakes and marshes, which – combined with plenty of volcanic eruptions – made an ideal environment for preserving large numbers of fossils, often in great detail. But that's not the only reason Liaoning is producing more fossils than any other part of the world today – China can also invest enormous manpower in recovering fossils. "Some of these localities are unquestionably very rich in fossils but ... the success is clearly linked to the almost unlimited labour available in China," says Luis Chiappe, director of the Dinosaur Institute at

the Natural History Museum of Los Angeles County. He describes the work being done there as the "paleontological parallel of the construction of the Great Wall of China".

Thousands of farmers have become "bone diggers" who find fossils and sell them to dealers. Although it is illegal their efforts continually yield new species. High-quality fossils can sell for tens of thousands of dollars, so when your monthly earnings total a few dollars or less finding one is akin to hitting the jackpot.

"Some Chinese museums have their own expeditions and go out to collect ... but the bulk of what is collected in China has entirely been dug up by the farmers," Chiappe explains.

Xu Xing – a professor based at Beijing's Institute of Vertebrate Palaeontology and Palaeoanthropology – agrees that many of the specimens from Liaoning have come from farmers and dealers, but adds that fossils he has described from elsewhere, such as Inner Mongolia and Shandong Province, have been excavated by his own team. He doesn't like to buy fossils and has bought fewer in recent years, but he's often faced with a difficult decision: if he chooses not to purchase an important fossil it could be lost forever to a private collection, on the other hand if he does purchase it, it encourages farmers to keep on digging.

Having thousands of farmers looking out for fossils is a double-edged sword. Though many more fossils are being discovered, they are collected and prepared in a way that destroys much of the scientific information. If scientists don't know which location and rock layers the fossils come from, they can't precisely pinpoint their age and struggle to confirm their veracity.

Knowing which geological layers of rock housed the fossils – the stratigraphy – is the key to dating them. Specimens dug up by farmers and sold on to dealers cannot be classified in this way.

02



Xu Xing, here standing with a cast of the parrot-beaked *Psittacosaurus*, was the Beijing-based palaeontologist who identified the hoax.

Chiappe says a study he is conducting on fossils of the early bird *Confuciusornis*, one of the most abundant fossils found in Liaoning, exemplifies the problem. His team has studied 180 specimens and have no option but to compare them as though all 180 lived at the same time.

“We treat them as a modern population, but they aren’t a modern population”, he says. “They have lived thousands, hundreds of thousands,

ANOTHER MUCH MORE SERIOUS PROBLEM, however, is posed by faked and manipulated specimens. The best-known example is the *Archaeoraptor*, named by *National Geographic*. The episode drew public attention to the scale of the problem, and also to the difficulty of identifying a fossil hoax.

The Chinese farmers who dig for fossils are well aware that complete and spectacular specimens

03

THE MOST
EXTREME KIND
OF FORGERY
TAKES
FRAGMENTARY
FOSSILS AND
CARVES OUT
THE MISSING
PARTS FROM
THE STONE.



Long-tailed male *Confuciusornis* – an early bird – with a female. Abundant in Liaoning, the specimens cannot be accurately dated when farmers dig them up without noting the rock layer they lay in.

maybe sometimes even millions of years apart.” If scientists had data on the precise age of the fossils, they might be able to look into whether the species had changed over time, and with better data on geographic location, they could look at changes between regions. “[But] we don’t know that, because we don’t know exactly where the fossils come from,” Chiappe says.

are worth far more than the fragments. Some don’t even realise they are faking specimens and combine pieces of different fossils found at the same locale. In the most extreme cases, this manipulation is intentional, involving fossils found at disparate locations. It sounds crude, but even the experts have to look carefully to detect the trickery when master forgers have been at work.

Fossils can be faked in a variety of ways. Sometimes they're hewn from parts from the same species but come from different individuals, so you might have a *Microraptor* skull, tail and body all from different individuals. Another method involves combining the parts of different species to make a complete fossil that appears to be a new animal. "Dinosaurs are very similar to birds, so sometimes these fossils combine different birds, different dromaeosaur specimens, or even birds with dinosaurs," Xu says. But the most extreme kind of forgery takes fragmentary fossils and carves out the missing parts from the stone.

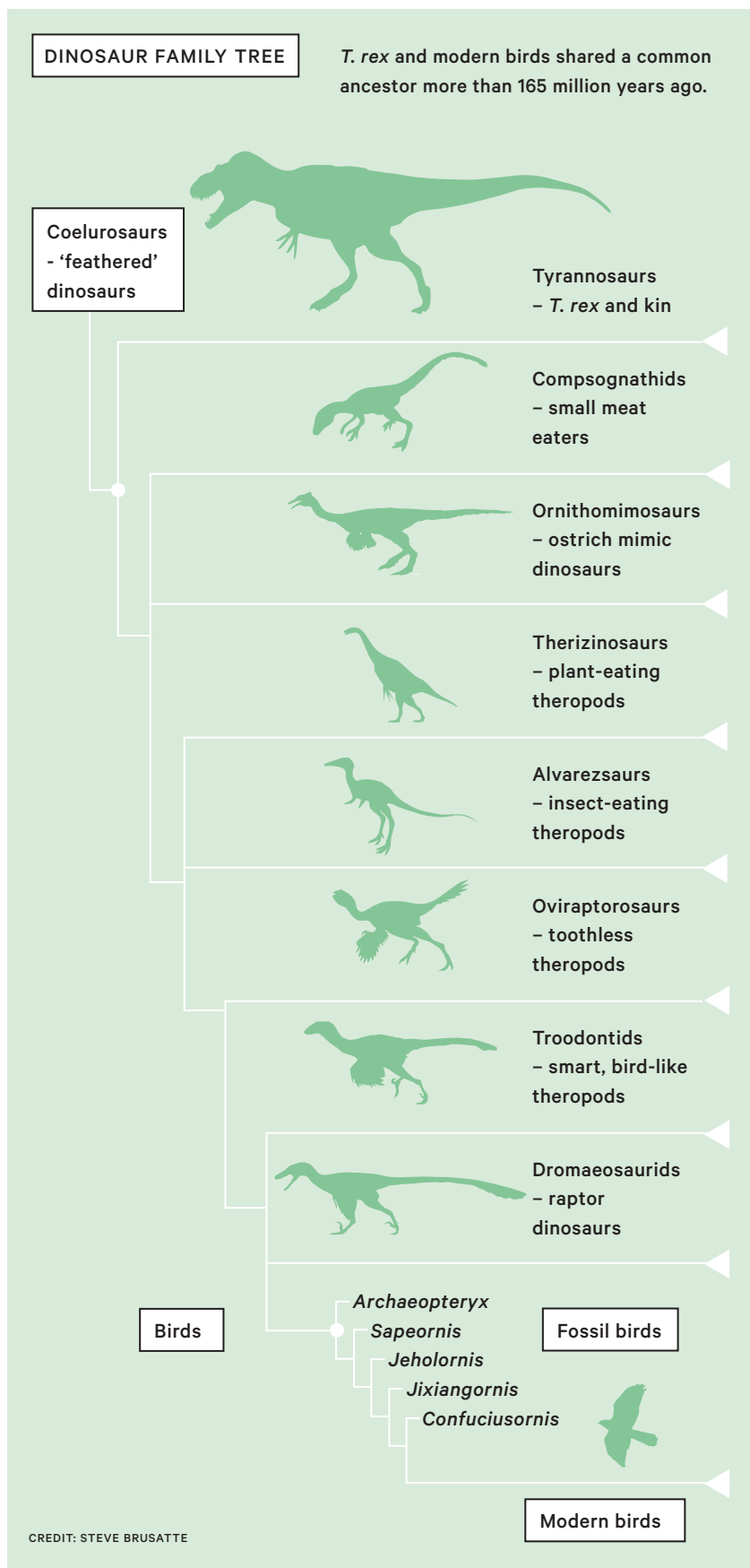
In rare cases fossils are completely manufactured from scratch. Palaeontologist Phil Currie at the University of Alberta in Canada saw one example in China while on a research trip with Xu. "He got a call that a very nice specimen had been found and it looked like *Archaeopteryx*," he says. "And so we flew to another part of China ... and when we got there, it took just seconds to realise that it wasn't a real fossil at all. It had been basically ground-up bone, glued back together in a certain way to look like the *Archaeopteryx*."

It's a significant hurdle to good science, and one that can't easily be solved.

AS PALAEOLOGY HAS BOOMED in China so has the museum sector, and new institutions cropping up across the nation have fuelled the market for specimens to fill them. Sometimes these institutions, especially small regional museums, have no trained scientists, and display many fakes alongside real fossils.

In Shandong Province, 100 kilometres south of Beijing, mineral magnate Zheng Xiaoting has used wealth amassed from gold mining to build the largest collection of complete dinosaur fossils anywhere in the world. The Shandong Tianyu Museum of Nature has more than 2,300 specimens of early birds (including around 600 examples of *Confuciusornis*) and more than 1,000 dinosaur fossils, including hundreds of feathered specimens, some described in the top journals *Science* and *Nature*. According to Chiappe, however, even wonderful museums such as this are not immune to the problem of fossil fakery. He believes many fossils at Tianyu have been purchased from diggers without documentation or detailed stratigraphic information.

Based on recent trips to China, Chiappe believes around 50% of specimens he's seen in regional museums have been enhanced. "Sometimes that's not important. It's just a little





04

The real deal: Technicians in Beijing preserve middle Jurassic dinosaur fossils from Wucuiwan, in Xinjiang province.

thing that you can highlight and say, ‘Well, the left hand was sculpted ... I’m going to exclude this from my study,’” he says. “But sometimes it’s more significant.”

Anyone working with Chinese specimens needs to have their eyes open to the risks. In the past, because of the difficulty of accessing the collections, some scientists analysed Chinese fossils based on photographs alone, but this is no longer good enough. “You need to have them under a microscope,” Chiappe says.

An investigative report published in *Science* in 2010 revealed that as many as 80% of marine reptile fossils on display in Chinese museums had been altered or manipulated. Unfortunately, there are few solutions to the problem of faked fossils in China. Laws that forbid the sale of fossils have stemmed some of the trade (they have harsh penalties – ranging from significant fines to execution – but are rarely enforced), yet much of it continues on the black market.

ANOTHER ELEMENT to the illegal Chinese fossil trade is the flow of important specimens overseas. In November 2010 the *China Daily* newspaper reported that, in the preceding three years, China had reclaimed more than 5,000 fossil specimens from foreign countries, including Australia, the US, Canada and Italy. A new law, which came into effect at the start of 2011, levied large fines against any person or organisation moving important fossils overseas without express permission from the authorities. Although there are a few exceptions, most major museums in Europe and the US have strict rules about acquiring looted fossils. Specimens from China and Mongolia (from where it is also illegal to export them) nevertheless routinely turn up for sale overseas.

A number of high-profile cases of illegal fossil trading over the last few years have brought the issue to the attention of the media. There was a blaze of controversy in May 2012 when a largely complete skeleton of a Mongolian *T. rex* relative, *Tarbosaurus bataar*, appeared for sale at Heritage Auctions in New York. Before the auction American Museum of Natural History palaeontologist Mark Norell wrote an open letter arguing that the fossil was clearly from Mongolia’s Gobi Desert and must have been obtained illegally. Despite an injunction brought by US lawyers employed by the president of Mongolia – and a restraining order from a district court judge having been delivered to the auction house that day – the fossil was sold for more than \$1 million.

Norell is certainly in a position to know the fossil was from Mongolia. He’s been digging up fossils there for two decades, working alongside the Mongolian Academy of Sciences, and has authored more than 75 papers on his findings. Although the auction went ahead, the fossil was taken into custody on 22 June by US authorities, who seized it from a storage facility.

In a strange twist of fate, the leg bone of another *Tarbosaurus* specimen appeared in the window of London auction house Christie’s at around the same time. Christie’s is just a short stroll from the Natural History Museum, where palaeontologist Paul Barrett works, and he spotted the fossil one day as he was walking past. Immediately suspicious as to its provenance, he wrote to Christie’s expressing his concerns. The auction house communicated this to the buyer and pulled the bone from sale.

Norell isn’t the only one to have noticed an insidious and growing problem. Phil Currie says he first realised that looting of fossils from protected sites was a serious issue in 2000, when specimens vanished from digs he had worked on for many years in Mongolia.

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05



Mongolia is cracking down on the illegal trade of dinosaurs like this Gobi Desert *Tarbosaurus*.

Though the *Tarbosaurus* skeleton that had been auctioned in New York was seized by US authorities in June 2012, the legal issues weren’t wrangled out until nearly a year later, when the fossil was returned to Mongolian officials. In a ceremony in a hotel across the street from the United Nations complex in New York, the dinosaur was symbolically handed back to Bolortsetseg Minjin,

a Mongolian palaeontologist who had been involved in the fight to stop the auction going ahead, and Oyungerel Tsedevdamba, Mongolia's Minister of Culture, Sports and Tourism.

The pair used the opportunity to announce that the fossil would be used as the founding exhibit for Mongolia's first dedicated dinosaur museum, the Central Museum of Mongolian Dinosaurs, where Bolortsetseg would act as chief palaeontologist.

In a speech, the minister said that before the controversy over the *Tarbosaurus* remains, Mongolians were vaguely aware of their paleontological heritage, but didn't have any celebrity dinosaurs to rally around — a situation

that was set to change with the fame generated by the skeleton. The creation of a national dinosaur museum and public interest and pride in its exhibits, was at least a silver lining to the cloud of the looting controversy.

Meanwhile, Eric Prokopi, the Florida fossil dealer who had prepared the *Tarbosaurus* for sale and auctioned it in New York, was jailed for three months in June 2014. He was also reportedly in possession of a number of other illegally trafficked specimens, including duck-billed hadrosaurs, oviraptorids and more *Tarbosaurus* remains. All of these are to be returned to Mongolia, as are the remains that were on sale at Christie's in London, which were sourced back to a British fossil dealer.

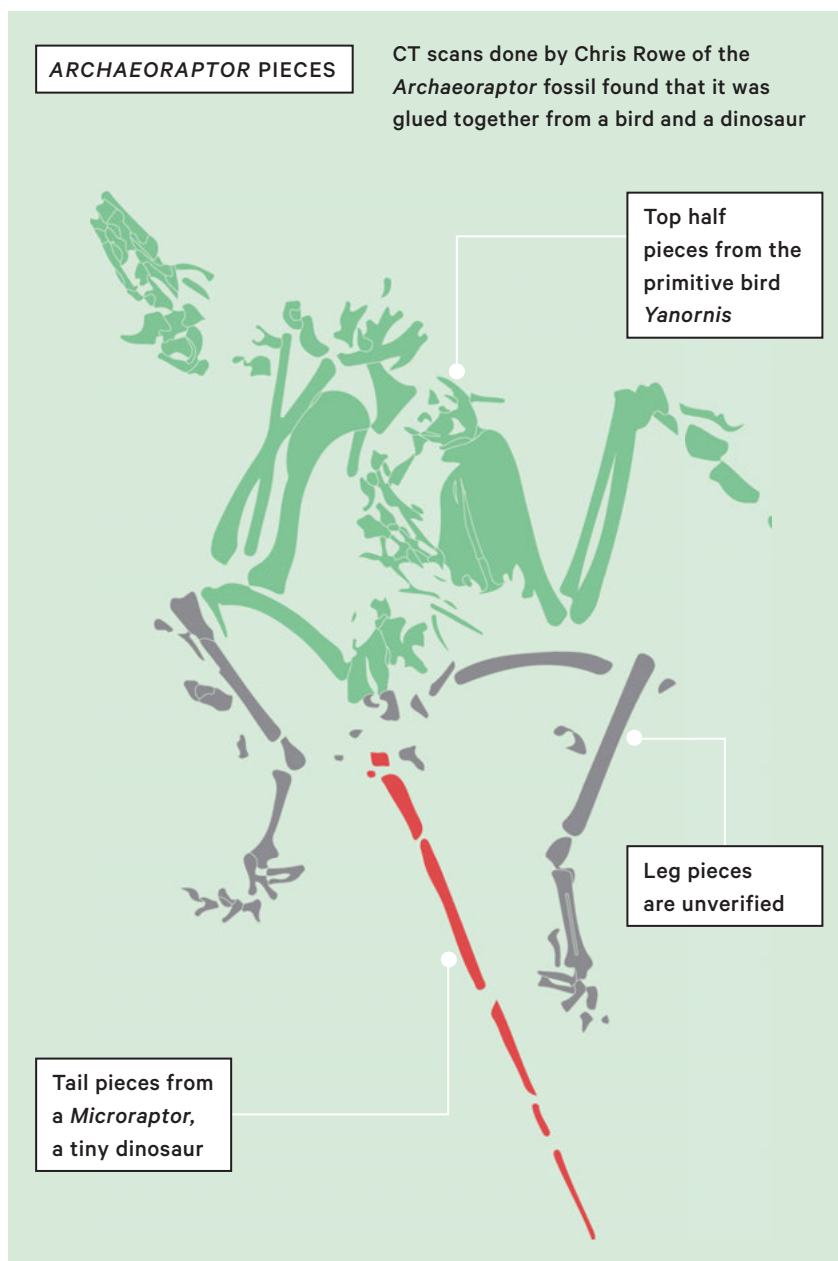
The significant media interest in the *Tarbosaurus* cases and the illegal fossil dealing has at least brought the issue to wider public attention and should make it much more difficult to auction this kind of material in the future.

But there's still a long way to go.

AFTER THE ARCHAEORAPTOR FIASCO that proved so embarrassing for *National Geographic*, the magazine's then editor Bill Allen, brought in journalist Lewis M. Simons to investigate. Simons reported in the October 2000 edition that it was: "A tale of misguided secrecy and misplaced confidence, of rampant egos clashing, self-aggrandisement, wishful thinking, naive assumptions, human error, stubbornness, manipulation, backbiting, lying, corruption, and, most of all, abysmal communication."

The American part of the story began with the smuggling of a fossil from China to the US where it was presented for sale at a major fossil show in Tucson, Arizona, in February 1999. There it was discovered and purchased by Steven and Sylvia Czerkas, well known paleo-artists and dinosaur enthusiasts who run a small museum in Blanding, Utah. They raised the \$80,000 required for the specimen from a backer and patron of the museum. The Czerkases were friends of Phil Currie, so they invited him to study the fossil and prepare a publication on it with them in a scientific journal. After an initial glance, palaeontologist Currie, who worked regularly with *National Geographic*, alerted senior editor for archeology and paleontology Chris Sloan, to the fossil. Sloan decided it was the perfect addition to a story on feathered dinosaurs he was writing.

The Czerkases had hoped to display the fossil in Blanding and that it might be the making of their



museum, but Currie and Sloan persuaded them that in order for the fossil to be studied and for anything to be published on it, it must be returned to China after they were finished with it. Once this was agreed, Xu Xing became involved and travelled from Beijing to examine the specimen before its return to China.

Alarm bells started to ring when Timothy Rowe at the University of Texas started to examine the fossil using X-ray CT scans. These allowed the researchers to examine the 3D structure of the fossil. Rowe, an expert at examining such scans, argued the specimen had been made from a number of fossils, and that the tail did not belong to the body. Currie agreed he had some concerns, but the Czerkases refused to believe there was a serious problem and pushed on for publication. Ultimately, both *Nature* and *Science* declined to publish a paper announcing a new species. This left *National Geographic* in the awkward position of officially doing so, as their print cycle and media machine were already too far ahead to pull the story.

In early 2000 Xu proved *Archaeoraptor* was a fake. He found a counter slab bearing the tail — a mirror image created when a fossil has been split down the middle into two flat slabs of rock — in an institute in China in early 2000. But it was attached to the legs of a tiny undescribed dinosaur. This proved that the tail belonged to another specimen entirely and had been arranged in a false position in the *Archaeoraptor* fossil.

Cue a retraction by *National Geographic*, which was then forced to launch an enquiry and bring Lewis M. Simons on board to carry out an open investigation. Phil Currie would later describe his involvement in this scandal as the “greatest mistake of my life”.

Subsequent detailed CT scans by Rowe revealed that *Archaeoraptor* was glued together from 88 pieces of different individuals fossils. Mostly they came from two species unknown to science, making the specimens important in their own right. The tail was from *Microraptor*, then the smallest dinosaur ever discovered, while the front half was a primitive bird subsequently named *Yanornis* in a 2002 *Nature* paper entitled “*Archaeoraptor*’s better half”.

Luis Chiappe says with hindsight it seemed obvious that the animal was a chimera of bird and dinosaur features, but it was put together with great skill.

Xu says that much has changed since then. At the time a forgery such as this was not only unexpected, but also difficult to predict. It’s also

likely that, in those early years following the discovery of *Sinosauropteryx*, the first feathered dinosaur, people were caught up in a wave of excitement and were perhaps less careful than they might otherwise have been.

“If you look at the background, this is a very complicated story”, he says, adding that it’s rare to find completely articulated specimens.

“In most cases when we do fieldwork in Inner Mongolia, in Xinxiang, or other parts of the world, what you find very often is an incomplete skeleton ... You see lots of bones on the surface and you collect those bones and go back to the lab. You need to figure out whether those bones are from one individual or from two individuals or from several individuals.”

EXPERTS ARE MUCH MORE WARY of inconsistencies or anomalies in fossils these days, but 15 years ago scientists assumed honest errors. Perhaps the specimen wasn’t assembled properly or some elements had been attached by mistake.

“At the time, in 1999, we were not really prepared to face the problem of composite or faked specimens,” Xu adds. “Today, if you see a specimen like that — especially if it’s from Liaoning — you will say, ‘Oh yes, this is definitely a fake specimen’, because you know that this is a really serious problem.”

China’s new fossil industry has appeared in the blink of an eye and its paleontological community is still finding its feet, but if Chinese authorities and museums are going to maintain their credibility, they will have to tackle the problem of faked fossils and the trafficking of fossils overseas.

A remarkable series of finds has given us a window into a weird and unexpected world, but the trade in faked, manipulated and illegally obtained fossils has tainted what are otherwise spectacular collections. ©

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JOHN PICKRELL is the author of *Flying Dinosaurs: How fearsome reptiles became birds*, published by New South.

IMAGES

- 01 O. Louis Mazzatenta / National Geographic
- 02 Stefan Crow
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- 04 Ira Block / National Geographic / Getty Images
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HUNTING PHONEY BURGERS

A race is on to manufacture tastier, more convincing synthetic meat. CORBY KUMMER reports on the efforts of modern-day alchemists.

→

ETHAN BROWN, a vegan who sold his home and raided his family's savings account to fund a start-up called Beyond Meat. The fake burger he is eating was produced by a machine he calls "the Steer".



PEOPLE WANT BURGERS. It seems hardwired. You can read Richard Wrangham's *Catching Fire* to learn how man evolved into a thinking primate by learning to cook the animals he killed. You can talk to the stylish proprietor of a leading cooking school in Japan, who co-owns an artful Manhattan sushi restaurant. What does he find the most efficient fuel for his triathlon training? A couple of McDonald's quarter-pounders a day.

VEGETARIAN AND VEGANS WANT BURGERS.

Walter Robb, co-CEO of the US company Whole Foods, says that from the time he started a health-food store in the Northern California of the late 1970s, he had to sell tofu, seitan (made from wheat gluten) and anything else that could be made to look like meat but wasn't. "The stuff sells," he says simply. Entire books are dedicated to veggie burgers, even if they all taste like over-seasoned, under-hydrated corrugated cardboard.

Of course, there are rational reasons not to eat meat. You can probably recite them along with Ethan Brown, a strapping 1.95 metre vegan who sold his house in Washington, DC, and raided his family's savings accounts to fund a start-up called Beyond Meat. Because raising livestock is such an inefficient use of land and water, he thought that making soy "chicken" strips and vegetable-protein "Beast" patties would be a better way to improve the environment than creating fuel cells — the career he abandoned. Along the way he signed up Bill Gates and Twitter founders Biz Stone and Evan Williams as investors. It's hard, in fact, to find a tech billionaire who hasn't invested in a protein alternative that aims to stamp out factory farming. They all recognise the realities of the market: everybody buys burgers. "Meat is such a macho thing," Williams says.

I eat meat. It's hard to be a restaurant reviewer, as I am, without eating meat. I like to think I'm less culpable if it has been raised with care, killed humanely (I'm still not clear about what this means, although from the time I started writing about food I've watched chickens, lambs and cattle be killed and butchered in farms and factories) and sold at

a price that allows fair wages to everyone involved with its production. But I have never tried to delude myself that more than the tiniest fraction of people who want meat can afford to keep these illusions of enlightenment alive.

The problem is that the new alternatives are — to quote tech billionaire and co-author of *Modernist Cuisine*, Nathan Myhrvold — only "slightly better Tofurky" (a turkey substitute made from tofu and wheat protein). So why bother? This was the question on my mind when I headed to Beyond Meat's office in El Segundo, California. Why kill yourself to produce a not-quite-rubber burger? Why not make something new?

BEYOND MEAT BEGAN when Brown ploughed through scientific papers to find the university researchers who were doing the work likeliest to advance the T in TVP—textured vegetable protein. Texture, Brown thought, was the key to a better meat substitute. He also wanted to vary the V: most TVP means soy, in a world where many people want to avoid genetically modified organisms and almost all soy is a GMO. His assumption was that the flavour challenge had been cracked by chemists working from the late 1960s through the '80s — a golden era for experimentation in processed food, when instruments to measure flavour were being invented and refined, multinational flavouring companies were racing to develop new molecules and cranks hadn't started talking about eating only what your grandmother ate.

The El Segundo offices, on a street in a quiet beachside neighbourhood with strip malls, seem less like a tech start-up than like the laid-back

domain of amiable tinkerers. The essential research tool is a clunky-looking machine Brown calls “the Steer”; its task is to convert vegetable proteins into “meat”. Product developers scoop white soy and pea protein meal that looks like animal feed from white plastic buckets into one end of the machine, along with water. “The Steer” then extrudes strips that the developers grab to see how moist and tearable they feel. A young man uses an eyedropper to squeeze liquid coloured with turmeric on to a Beast patty to see if it can stay in the burger during cooking and create the look of myoglobin, a protein in muscle cells. The test kitchen has an open pantry of wire shelves filled with spices and starch powders only slightly more obscure than what you’d find in a supermarket, and a stove that could have come out of a rental apartment.

Meat is the hardest problem for flavour-chemical companies to solve says Don Mottram, an emeritus professor of food chemistry at the University of Reading in the UK. Because of its complex structure, meat develops flavour at different rates as fat, muscle and bone cook successively.

Mottram spent decades investigating meat flavour and in particular the Maillard reaction, the caramelisation of carbohydrates that releases hundreds or thousands of compounds during cooking.

Anderson approaches flavour like a cook: by constantly experimenting with the proportions of ingredients. He gamely warms up some Beyond Chicken “lightly seasoned” strips, Beyond Beef “beefy crumbles” and a Beast Burger for me to

**WHY KILL
YOURSELF
TO PRODUCE
A NOT-QUITE
RUBBER
BURGER?**

02



Cooked burger patties produced by Beyond Meat from white soy and pea protein meal. Achieving the taste and texture of real meat is proving a challenge.

Dave Anderson, a friendly, slightly shaggy chef, ran a popular vegan restaurant in Los Angeles, where he was particularly proud of his portobello mushroom bacon and his seitan poached in mushroom broth (“you could tear it like filet mignon”). Brown may have assumed that flavour was the easy part and texture the hard part, but Anderson has learned from trial and error that both are high hills to climb.

taste against their real-meat counterparts — something that he and the rest of the flavour developers, including the die-hard vegans, regularly do (they figure that giving fellow vegans better alternatives will make up for any lost karma).

I’m impressed by the “lightly seasoned” strips insofar as they bear a strong similarity to my Hungarian grandmother’s Saturday lunch of re-boiled chicken from her Friday-night chicken soup.

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She used garlic and onion in everything, too much salt, and usually some dried or fresh parsley. So does Anderson. What took her hours of simmering for a particular waterlogged yet dry, chewy texture, Beyond Meat achieves by tossing pieces of extruded soy protein into a flavoured brine under a vacuum, so the liquid and flavour will penetrate better.

We compare the taste to pre-packaged supermarket brand chicken strips – the standard Anderson says he is aiming for. Their chewy fibrous texture is more unmistakably meaty than that of the Beyond Meat strips, though the strips are pretty close and getting closer. Tim Geistlinger, who's in charge of R&D, lets me sample a new batch of "chicken" strips, which have a more complex texture. With better hydration, it will be possible to confuse these strips with the supermarket chicken strips. I went through the better part of a bag of Beyond Meat strips without really thinking about it. And I'd certainly rather eat what Beyond Meat manufactures than supermarket chicken.

Brown eat some, he added ketchup, sliced tomato and iceberg lettuce.

What's most striking is not how close these products are to supermarket chicken strips and ground beef but how debased our own flavour sense has become. If Bill Gates and other luminary investors in Beyond Meat can be fooled, as they say they have been, it may be because they have a degraded sense of what actual chicken or steak tastes like.

After my day of tastings, I went to Cut, one of Los Angeles's most expensive steakhouses, in the Beverly Wilshire hotel. There's nothing like a steak with the intramuscular marbling fat that bastes every bite of a bone-in porterhouse: tender loin with sinew and cartilage for texture, and a heavy fat cap that is like a food group of its own. Beyond Meat and its rivals are decades away from achieving anything like it.

My table ordered so much steak that Cut gave us some kobe beef sliders. Once you scrape away the ashy char and ignore the house-made ketchup

03



A Beast Burger with the lot. The relative dryness of the Beast can be remedied with typical burger dressings, lettuce and tomato. The taste of nutrient powder in the Beast needs to be disguised too.

The Beast is more problematic. It has to be tarted up with a lot of seasoning – more onion and garlic, paprika, mesquite, sugar – to cover the taste of the nutrient powder it contains. (The powder is there so that Brown can claim that the product has more iron and protein than the same amount of ground beef, more omega-3s than the same amount of salmon.) And the Beast isn't moist enough – you need a good bit of liquid to get it down. When I saw

and freshly baked brioche bun, the chewy gristle isn't so far from the dry, flavour-free crumbs of supermarket ground beef Anderson plunked down beside the Beast. Plain ground beef is dismal. With some essential work on flavour and moisture, Anderson and Geistlinger will be able to get beyond the cooked dog-food appearance of the Beast. They might even perfect the Salisbury steak – a dish made from ground beef and other ingredients and

served with gravy. Anderson says he can imagine achieving a substitute for this US school-cafeteria staple in his lifetime (he doesn't mention the school-cafeteria part). Both men are also confident that the skinless chicken breast might not be far away.

Another alternative — test-tube meat, also known as cultured meat, in vitro meat and lab meat — is probably decades off, despite the introduction of a \$332,000 burger at a London press conference in August 2013. The pinkish ground meat had been produced in a Maastricht University lab directed by Mark Post, a vascular biologist and surgeon: it consisted of billions of cells cultured from skeletal muscle cells taken from one beef neck, nourished in a warm broth of synthetic nutrients and cow-foetus serum. To get the cells to grow into myotubes, the building blocks of muscle fibre, the researchers reduce the serum in the broth, which causes the cells to stop dividing and fuse. Then they suspend the cells in a gel surrounding a central column that allows them to align and form muscle fibres. For the scaffold, Post and others first used Velcro and then searched out biodegradable options. At the live-streamed tasting, the testers reported that the burger tasted almost like a real one, but not as juicy and was “surprisingly crunchy”. (The burger backer was Google co-founder Sergey Brin.)

More practical-minded researchers based in Brooklyn, New York, are aiming to produce cultured meat at a company called Modern Meadow (the names of these companies, you will have noticed, border on the Orwellian). Gabor Forgacs, a theoretical physicist who changed midcareer to developmental biology, and his son, Andras, are incubating beef cells and mixing them with pectin and spices to create a range of products, including “baked steak chips”. Their original company, Organovo, intended to produce living tissue for drug testing; food seemed to be an equally achievable goal. Of course, Modern Meadow has its own Silicon Valley angel: PayPal co-founder Peter Thiel.

In theory, the production of cultured meat can be scaled up. The result may be closer to real meat, including its complex flavours, than any other inventions in the works. But it is still in the basic research phase. The problems are many: scientists must figure out how to build intramuscular fat, sinew, cartilage and even bone, as well as a structure to mimic veins and blood vessels that will keep the cells fed so they don't become gangrenous.

The work is so expensive that the steps forward are likely to come from trying to produce organs

for transplant — which are “worth millions of dollars a pound instead of \$10 a pound”, as Myhrvold points out.

NONE OF THIS WILL DO MUCH for people who care about cuisine. Fooling more people by coming closer to debased industrial meat does not represent a step forward for the discerning diner. Admittedly, none of these companies is aiming to cater for the connoisseur. But for people who do care about flavour, some of the new research could result in actual improvements.

I'm interested in seeing how cooks will use these companies' protein-isolation techniques to create entirely new textures. Two ethereal dishes pointed the way for me. I tried them during a competition among practitioners of washoku, a Japanese cooking philosophy that glorifies the pleasant savoury taste of umami, with results from the simple to the exquisite. One was a pyramid of trembling, subtle sesame tofu, a Kyoto specialty of Buddhist monks. Flanlike, with the musky flavour of toasted sesame and light soy, it didn't attempt to be anything but delicate, and it was unlike any tofu I'd had anywhere, including Korean restaurants that make fresh batches every few hours.

The other was a small white bowl of luminescent white tofu as reconceived by Rene Redzepi, Lars Williams, and their staff when they set up an outpost of the Danish restaurant Noma in Tokyo last winter. It was the one classic Japanese dish they dared try to make. Tiny corkscrews of soft, beige grated unripe walnut coated it like snow; an emerald-green herb sauce lay at the bottom. The tiny cube of tofu didn't quite taste of milk or soy, though it was reminiscent of both; it was silken air, the clear expression of a passing if intense notion of what fresh tofu could be. In the hands of cooks capable of that kind of imagination and high-wire skill, pea-protein isolates — even fortified with omega-3s and iron — can be the way to save the world and keep it safe for culinary invention, too. ☺

CORBY KUMMER is a US-based food writer.

CREDIT: MIT Technology Review

IMAGES

01 Jeff Minton

02 Jeff Minton

03 Jeff Minton

ON THE RIGHT SIDE OF HISTORY

Not one to duck for cover, Alan Trounson has braved fiery social conflict to deliver IVF and embryonic stem cells to the clinic. Now he's set his sights on treating cancer. ELIZABETH FINKEL reports.



ALAN TROUNSON has just spent seven years leading California's \$3 billion push to turn stem cells into cures.



ALAN TROUNSON HAS FACED DOWN a charging black rhino. It is not the worst confrontation he has experienced during an eventful career.

HE DOESN'T
LOOK BACK;
HE ONLY
SEES GREEN
LIGHTS.

IN THE 1980S Trounson transformed in vitro fertilisation (IVF) from a hit-or-miss procedure into the routine treatment that has brought some five million babies into the world.

In 1998 his team was one of the first to capture the immortal stem cells that exist so fleetingly in the developing human embryo. These pioneering technologies made Trounson the target of incensed Catholics, feminists, politicians and journalists. Trounson faced each onslaught, shrugged off the bruises and moved on to the next challenge.

There was no shortage of charging rhinos during his seven years as President of the California Institute of Regenerative Medicine (CIRM) – the world's biggest, boldest push to enlist embryonic stem cells in the fight against human disease. When Trounson left the post last year to spend more time with his family in Australia, the report card was positive. An external review in 2012 found: "Overall, CIRM has done a remarkably good job." Jonathan Thomas, chairman of CIRM's board, praised him as "a remarkable leader" and "the driving force behind some truly innovative ideas". "He brought the right personality skills; he made CIRM come alive and spread its wings," offered Evan Snyder, a neuroscientist at the Sanford-Burnham Medical Research Institute.

Trounson is now back home. But at the age of 69, he is *not* contemplating the quiet life. The man whom colleagues describe as "a force of nature" and "with a sixth sense for sniffing the next breakthrough" is leaping into another challenge: harnessing the immune system to fight cancer. "I've had a fantastic time for the last seven years amongst the 'can-do' people of the world," he says. "It's infectious."

SO WHAT'S THE SECRET of this "force of nature"?

Hard to say. Trounson is not given to introspection. "He doesn't look back; he only sees green lights," says Martin Pera, a long-time colleague and program leader of Stem Cells

Australia. Trounson's playwright daughter, Kylie Trounson, looked for answers in *The Waiting Room*, her recent play that delved into the maelstrom surrounding her childhood in the early days of IVF. Much of the play focuses on the anguish of infertile couples – the willing guinea pigs who became central players in IVF's transformation from a 1980s experiment to today's routine procedure. Schooled by Trounson in the fine points of human embryology, the couples encourage him to keep going despite failure after failure. "Were they selfless or selfish?" the playwright asks of the audience. And what of Trounson himself – selfless or selfish? The young Trounson's (now ex) wife Sue and daughter Kylie barely see him – he spends his days and nights at Queen Victoria hospital, waiting for women to ovulate their single egg so that he might fertilise it in the test tube and nurture the embryo. The Trounson of the play is an endearing, absent-minded scientist – quintessentially of the Aussie kind with his easy-going, plain-speaking manner. There's not a drop of pretension in him. Yes, it's Trounson through the prism of a daughter's love. But it's a fair depiction.

You might search for more clues to the man by probing into his childhood. But you won't find a youngster burning with ambition to solve the great problems of medicine. He tells me he was a pretty average student, with a huge passion for animals and was "always going to be on the farm". But he does share one telling anecdote. When he was about nine years old, his scout group was hiking in the Blue Mountains when a fire broke out. His team had already walked out but another was trapped. Some of the boys tried to outrun the fire up the mountain and died. Others ran down the valley back through the flames – and survived.

"I thought that's a pretty important lesson in life – that running away from something dangerous doesn't really help. What you've got to do is figure out the best way to survive, and sometimes that's running back into the fire."

Trounson ended up solving the problem of women's fertility after his own ambitions were hijacked. Like many Australian agricultural scientists of the 1970s, he was primarily concerned with the fertility of merino sheep. Their fine wool drove the nation's economy, but while other breeds often gave birth to two lambs or more, merinos delivered only one. Trounson discovered that was because they ovulated a single egg. So he developed hormone treatments that increased the number of eggs released. He also learnt to fertilise eggs in the culture dish, split them and reimplant them into the sheep uterus to create twins or triplets.

But Wood had little success. When he heard about Trounson's achievements, he drove out to the town of Jerilderie in rural New South Wales to recruit him. Ultimately he succeeded, although not until Trounson – who had become a rising star of animal embryo research – had done a stint at Cambridge learning how to multiply valuable cow embryos by splitting them and freezing them.

Wood's team with Trounson in tow became phenomenally successful. They produced the third IVF baby in the world in 1980. But it was still a hit-or-miss procedure. Trounson then introduced the techniques he'd used in sheep,

02



Proud fathers of IVF: Trounson, centre left, and obstetrician Carl Wood, centre right

Meanwhile, at Melbourne's Queen Victoria hospital, flamboyant obstetrics professor Carl Wood was tackling the problem of women's infertility in a not dissimilar way. His patients often presented with blocked fallopian tubes – the funnels that whisk an egg from the ovary to the uterus and where the rendezvous with sperm takes place.

Fertilising the egg in the culture dish and planting the embryo into the uterus would bypass the problem.

such as hormonal stimulation to trigger the ovulation of multiple eggs. He also kept the fertilised embryos growing in the test tube for several days to prove themselves, so that only the most robust could be selected for implantation. These methods revolutionised IVF's success rate.

Today the procedure is so routine it may come as a surprise that the birth of IVF was controversial. Wood and Trounson were vilified in graffiti as "baby killers". The charging rhinos they faced down included a strange mix of "right-

03



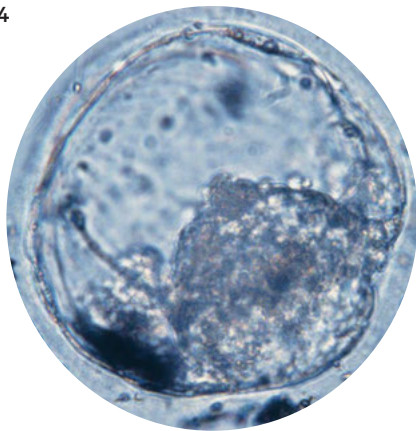
Trounson with daughter, playwright Kylie Trounson. Her play *The Waiting Room* explores the turmoil over IVF that surrounded her childhood.

to-lifers”, feminists and politicians.

The experience taught Trounson how to deal with confrontation. “You have to believe in yourself. And then have mentors like Carl Wood around who are pretty strong characters. They showed me that you could easily deal with it by just walking on.”

PERHAPS, BUT NOT ALWAYS. Trounson established a lab at Monash University to build on the IVF techniques he’d developed. They forged ahead with embryo freezing, so that women need not implant all their fertilised embryos at once and could avoid the risks of multiple pregnancies. They pioneered embryo biopsy techniques to identify embryos that might carry defective genes, and they learnt to give struggling sperm a helping hand by injecting them directly into the egg.

04



A human blastocyst, the controversial source of embryonic stem cells.

Then in 1995 this research was shut down by fiat of the state of Victoria’s Catholic health minister Marie Tehan. Even Nicholas Tonti-Filippini, a high-profile Catholic ethicist and vocal opponent of IVF, was appalled by the lack of democratic process. Many of the expert researchers from Trounson’s lab relocated overseas which is where these techniques were finally developed. All are now a routine part of the services offered by Australian IVF labs.

Trounson’s Monash lab switched focus to animal reproduction. A pet project was IVF for the endangered black rhino, which is how he came to be charged by one of them. While visiting a breeding park in South Africa, he sidled up to a sleeping hulk for a close-up shot when the camera’s automatic focus whirled and woke the beast. Trounson escaped narrowly thanks to the guide who let off a flare.

Research on human embryos had to move offshore. Trounson started collaborating with researchers at the University of Singapore. And then, some time in the early 1990s, his imagination was captured by embryonic stem cells.

RESEARCHERS HAD LEARNT how to cultivate these cells from mouse embryos. Like the embryo itself, they had the potential to form any tissue of the body. If the same cells could be cultivated from human embryos, the possibilities were dazzling. Once moulded into tissues and organs, they might provide spare body parts to replace those impaired by disease. Alternatively, model human tissues such as heart or liver, the ones most often damaged by drugs, could be used to test the safety of new compounds. But although researchers had tried for more than a decade, human embryos would not yield their stem cells.

Trounson recruited stem cell expert Pera from Oxford, who had trained Benjamin Reubinoff, an Israeli obstetrician on sabbatical in the lab. Reubinoff went to Singapore to work with human embryos and managed the feat. And so Trounson shot to fame once more. His team succeeded in isolating human embryonic stem cells in 1998, shortly after a group at the University of Wisconsin. But Trounson’s team had a possible strategic advantage. The US government, dominated by religious conservatives, had strangled funding for human embryonic stem cell research.

The challenge for Australia was to reap the rewards of the discovery. Trounson took to the hustings to convince the public and politicians. Embryonic stem cells would not only transform medicine, they could be the rocket to launch Australia’s sluggish biotech sector.

The rhinos charged. They included religious conservatives in the media and government, ethicists, feminists and many who simply felt unhappy about using human embryos in this way — even though surplus frozen embryos from IVF clinics, the proposed source of the embryonic stem cells, were being thrown into the garbage.

A tumultuous year followed. Trounson convinced the prime minister of the day, John Howard, that this was Australia’s chance to stake a major claim in pioneering research.

He won \$45 million to establish a national centre of excellence for stem cell research. But before the centre’s work began, Trounson became the target of a smear campaign. The accusations ranged from assertions that he had misled politicians about the details of the science to

EVERY TIME
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CIRM
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conflicts of interest, all claims that were fully cleared by an independent investigation. Finally in December 2002, after a four-month delay, the Australian Stem Cell Centre (ASCC) was relaunched.

But it was no plain sailing. Seven different institutes were involved in the brave new centre, each with different ideas about what course it should chart. Should it be a voyage of discovery, or should they narrow the focus to developing one particular therapy?

It was a stormy environment and Trounson's vision – closer to research than development – lost out. "History will show whether I got it right or wrong," Trounson told me at the time. A year into the life of the ASCC, Trounson left.

He started the Monash Immunology and Stem Cell Laboratories from scratch but had to compete for funding along with many other hopeful lab heads, some of whom were growing increasingly resentful that resources for stem cell research had been hijacked by the centre.

05



Arnold Schwarzenegger, the former governor of California, examines human stem cells. His support of stem cell research helped establish the California Institute of Regenerative Medicine.

Was Trounson right about the ASCC? The centre certainly delivered excellent research and brought together multidisciplinary teams that pioneered the ability to grow the volumes of stem cells required for a clinical trial. Ultimately, however, striking the right balance between basic research, developing a therapeutic product, and keeping everyone happy was a tall order. The divisiveness in the leadership weakened the operation. The ASCC shut down in 2011 when

it was unable to win further funding. By then Trounson had already moved on to far, far greener pastures. But that's not to say it was any kind of pastoral scene.

MARTIN PERA SHUDDERED when he heard Trounson was taking up the presidency of the California Institute of Regenerative Medicine. Pera had relocated to California in 2006 to become director of a stem cell research institute at the University of Southern California in Los Angeles.

"There isn't a day the CIRM leader doesn't have someone angry with them," he says. "From patient advocates to scientists, every time you make a decision, you brush someone the wrong way."

Once again, Trounson was entering an inferno where science, politics and religion intersect. But this time there was an extra element to this combustible mix: an astronomic level of public expectation.

Three years earlier, Palo Alto real estate financier Robert Klein had convinced the citizens of California to spend \$3 billion on stem cell research over a decade to usher in a new age of medicine. The US federal government had vetoed funds for embryonic stem cell research and a small group of politically savvy Californians decided it was time for people power. Some, such as Klein whose son has diabetes, had sick family members. In 2004, they mounted a successful ballot known as Proposition 71 to sell bonds to raise the money. However a legal push from the usual rhinos had stopped the funds by arguing that Proposition 71 was unconstitutional. Arnold Schwarzenegger, the governor who championed the initiative, helped with a loan until the courts overruled the objection. The bond money finally began to flow in late 2006.

CIRM was finally free to usher in the new age of regenerative medicine. It was not only a matter of spending money. California boasts some of the world's best scientists – places such as the Salk Institute, Stanford, California Institute of Technology and the University of California are studded with Nobel Prize winners. But the pipeline for delivering cures that worked in the lab to the clinic had not been built. "Oh to be a rat", quipped the late Christopher Reeve, the actor who played Superman and became paralysed after falling from a horse.

The obstacles faced by stem cell researchers had been clear for some time. To achieve the big goals, such as curing paralysis or diabetes, researchers must work together in a focused way,

just as they did to put a man on the Moon or read the human genome. But the academic system was geared for competition, not collaboration.

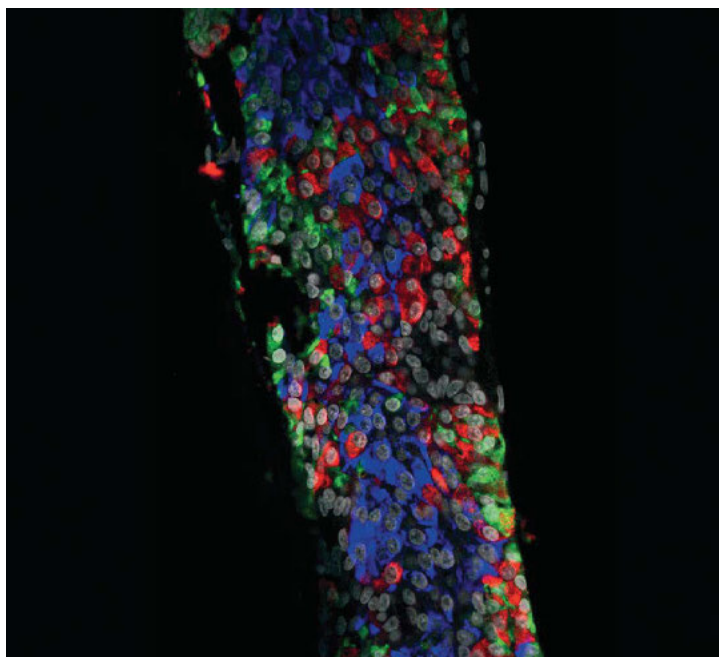
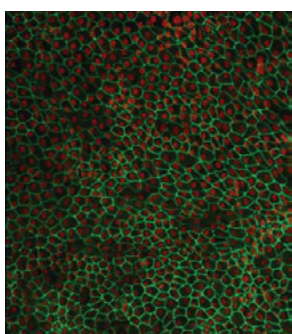
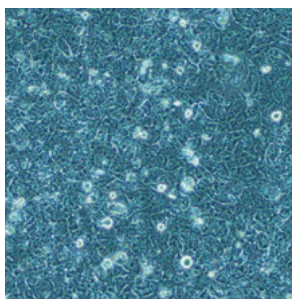
And then there was the “valley of death”. Taking a rat cure into clinical trials is extremely costly, and not something that is covered by research grants. On the other hand drug companies aren’t prepared to take a punt on laboratory research until early-stage human trials show promise. So many a promising rat cure never makes it across the chasm.

Trounson told *Nature* magazine in 2008. “Because if every single stem cell treatment costs \$800 million, we’re just never going to get there.”

CIRM might or might not get people out of their wheelchairs but it would certainly get stem cell medicine out of its paralysis.

By the time Trounson arrived, the basic operation was underway. Twelve new buildings were going up, necessary because researchers could not carry out embryonic stem cell research

06



Human embryonic stem cells (top left) have been trained to produce insulin-producing cells (right) and retinal pigmented epithelial cells (below left). Funded by CIRM, the insulin-producing cells are being trialed in people with type 1 diabetes; the RPE cells are being trialed for blindness caused by macular degeneration.

When it came to stem cells, the valley of death was wide indeed. Training stem cells to produce spare body parts was no easy matter. There were also huge concerns about the potential of stem cells to run amok and cause cancer. The well-established procedures for checking the safety and efficacy of new drugs did not yet exist for stem cells. By 2007, several stem cell companies had already come and gone, unwilling to wear the high level of risk. Even the pioneering company Geron, that had paved the path for trials on spinal cord injury, abandoned their efforts in 2011. Rising up in their place all over the world was a series of snake oil clinics, promising unproven stem cell therapies to desperate patients. CIRM would be the knight in shining armour galloping in to rescue the promise of stem cell therapy. “We have to be an instrument of change,”

in federally funded facilities. The research to be carried out in the new institutes was evaluated first by an expert panel of scientists from outside California. The winning proposals were then put to a 29-member board with an Orwellian title: the Independent Citizens’ Oversight Committee (ICOC). With the ICOC as the jury, Trounson was the presiding judge, charged with convincing them of the relative merit of the proposals. These hearings took place every two months – all under the intense gaze of the media.

If your mission is to spend \$3 billion of public money wisely and deliver cures and biotech businesses in a short space of time, there is bound to be conflict. And there was. Trounson’s predecessor Zach Hall had quit. Then chief scientific officer Marie Csete left in 2009. In a replay of what

TROUNSON LEARNED IN A BIG WAY FROM HIS DIFFICULT EXPERIENCES IN AUSTRALIA.

Australia experienced with the ASCC, a major point of conflict was deciding where to focus efforts along the spectrum from basic to applied research.

The ICOC board members – scientists, patient advocates, business people, Hollywood representatives – had differing ideas. Achieving consensus was a formidable task. And the entire process was as transparent as a reality TV show, with a website dedicated to dissecting every wrinkle. Nevertheless they were able to agree on the funding of some 800 projects. “In the end I thought it was a useful way to run an organisation like that,” Trounson reflects.

Many have noted that Trounson’s easy-going Aussie personality was a helpful lubricant. “One of the key features of his extraordinary leadership was the seamless integration of patients, industry and researchers into a harmonious, synergistic union,” says Jeff Sheehy, a board member and an HIV patient advocate. “One thing’s for sure – Trounson learnt in a big way from his difficult experiences in Australia,” notes Pera.

Besides adjudicating the hearings, Trounson set about building crucial pieces of the medical product pipeline. At the early end, this included establishing a Genomics Centre to decode the unruliness of stem cells by reading their DNA. It was also a requirement that all the research findings had to be rapidly published, and any cell lines and materials made available for sharing.

Trounson also established Disease Teams – the middle section of the pipeline. They were composed of lab scientists, doctors and companies who joined forces to tackle a specific disease. “I’m proudest of those,” says Trounson. Like a biotech company, the teams had to meet draconian milestones every six months for funding to continue. They were overseen by the consummately experienced Ellen Feigal, who Trounson spirited away from her post as medical director for the biotech giant AMGEN. At the end of the pipeline were the Alpha Clinics, specialised to deal with the medical requirements of stem cell trials. Trounson says they were modelled on the first Australian IVF clinics.

CIRM also completed the path for stem cell clinical trials that Geron had started. The US Food and Drug Administration knew how to deal with stable drugs. But stem cells were quixotic. For each cell type, what tests were required to ensure the cells were stable, safe and of the right type to replace the diseased tissue? The criteria for cells to repair the spinal cord, for instance, would be different to those required to replace a failed pancreas.

At the time of writing, CIRM has 20 clinical

trials at various points in the pipeline. They tackle a vast range of illnesses. Some use embryonic stem cells as spare parts. Trained to secrete insulin, they are being grafted into patients to treat type 1 diabetes, or as retinal pigmented epithelial cells to treat a form of blindness known as macular degeneration. Other trials use stem cells to find new drugs. For instance some types of cancer are driven by cancer stem cells that resist radiation and chemotherapy. By isolating these stem cells, researchers have developed new drugs to target leukaemia and breast cancer.

For many, this is a dazzling success story. Pera thinks back to the early 2000s in the Monash lab when they first managed to produce little patches of black cuboidal cells from embryonic stem cells – the same types of cells that his former lab in Southern California is now testing in the eyes of people with macular degeneration, thanks to CIRM. “Within five years, we had a clinical trial. I couldn’t see that happening anywhere else.”

Will the trials pay off in new treatments? It seems a premature question – most take closer to 20 years to develop. But CIRM must answer the question soon. After 10 years, the funders of Proposition 71 are getting restless for a return on their investment.

As for Trounson, his sights are fixed on importing CIRM’s can-do attitude back to Australia. Inspired by the success of new cancer treatments that mobilise a person’s immune system, he is gearing up to build a cancer “Disease Team” on his home turf.

And he’s in a hurry: “I don’t have another 20 years.”

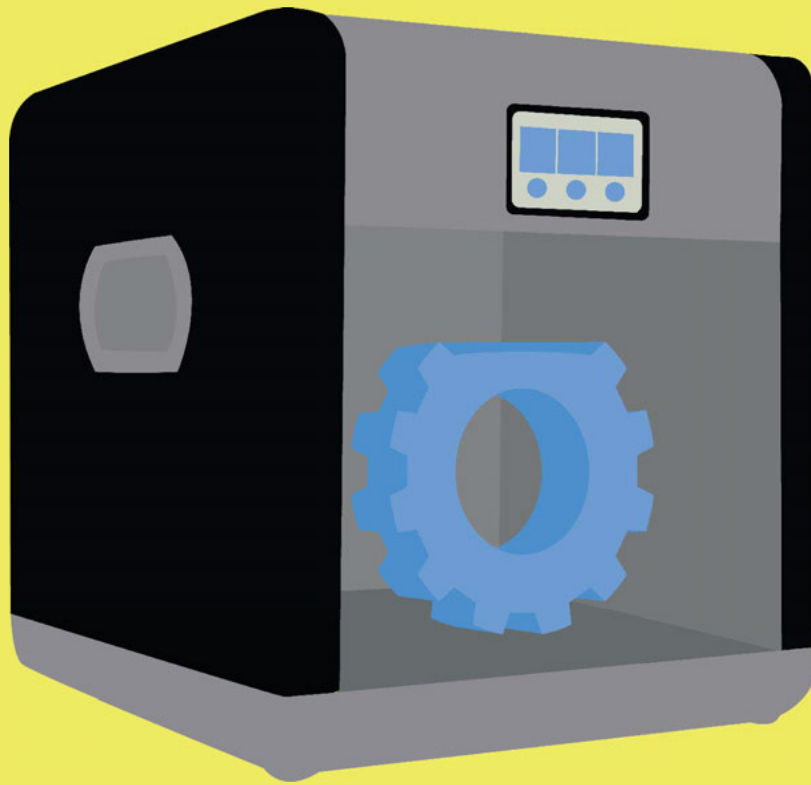
At least this time there shouldn’t be too many rhinos. ☺

ELIZABETH FINKEL is the editor-in-chief of *Cosmos* magazine and the author of *Stem Cells: controversy at the frontier of science* (2005) which includes a chapter on Trounson’s early research. bit.ly/StemCellBook

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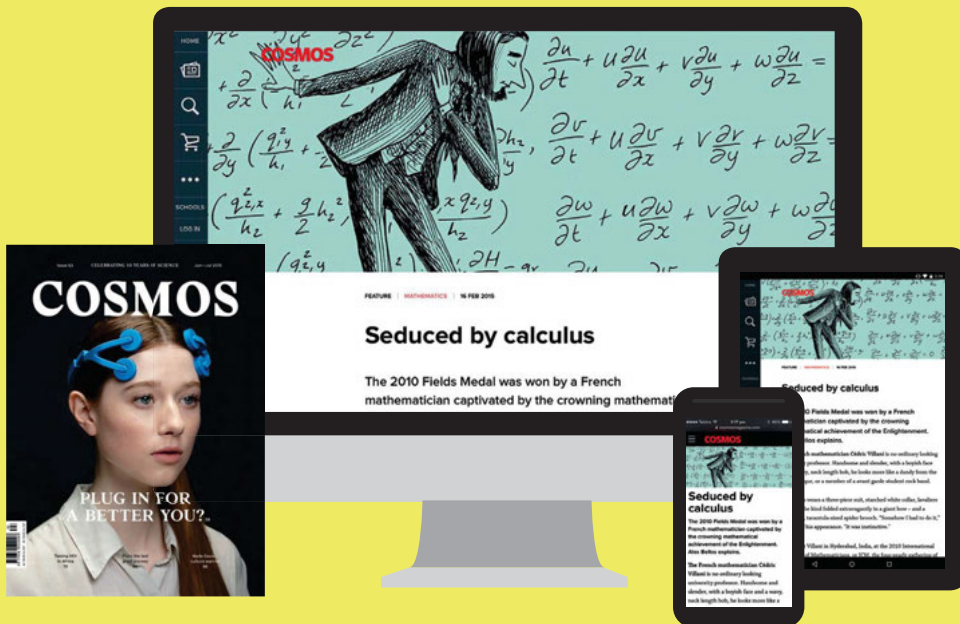
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PEOPLE, CULTURE
& FICTION

SPECTRUM



ZEITGEIST

Astrophysicist superstar

ANDREW MASTERSON talks to cosmologist
Neil deGrasse Tyson before his Australian tour. →

ZEITGEIST

Astrophysicist superstar

→ As every high school student knows, the “Goldilocks zone” is the middling distance from a star that is neither too close nor too far away to rule out the possibility of liquid water — and hence life.

To New York-based superstar astrophysicist and cosmologist Neil deGrasse Tyson, however, it’s an idea with significant flaws. Jupiter’s moon Europa is way out in the Solar System’s Mama Bear territory, but Tyson, like the folks at NASA, sees it as a prime candidate to bust the Earth’s reputation as the only biological game in town.

“Europa is a system that’s kept warm, not from sunlight,” he says. “We all learned that life requires sunlight, but really it only requires energy.

“Europa is outside of the Goldilocks zone, but it’s kept warm by Jupiter’s gravity. Beneath the upper surface of ice there’s a liquid ocean that’s been like that for billions of years. On Earth we know life began in the oceans — so if you’re a betting person, that’s the place to put the money. The best guess is right there, for sure.”

“WE’RE JUST AN ACCIDENT. WE DERIVED FROM A RODENT-LIKE CREATURE SCURRYING UNDERFOOT OF T.REX 65 MILLION YEARS AGO.”

Tyson, like Stephen Hawking, Albert Einstein and very few others, is one of those rare scientists whose reputation extends far into popular culture. His position as director of New York’s Hayden Planetarium and his hosting role on the Fox-TV series *Cosmos: a space-time odyssey* (a reboot of Carl Sagan’s program) both ensure high status in his field.

However, a short video clip of him saying “We’re dealing with a badass here!” excerpted from a TV appearance, long ago went viral and now crops up on social media sites not even vaguely related to the Universe. The clip has been divorced utterly from its original context — a reference to Isaac Newton — but as a result the astrophysicist is now a constantly circulating meme.

One US interviewer, Joshua Topolsky, recently suggested that the last comment page ever published on Facebook, “the day before the Sun explodes”, will have embedded in it the moving image of Tyson yelling “we’re dealing with a badass here!”.

Tyson, perhaps wisely, goes nowhere near the life of Newton during our conversation. He is, however,

happy to acknowledge another physicist, Brian Cox, with whom in 2013 he conducted a hilarious Twitter exchange about the practical flaws in the idea of light-sabres.

In 2014, Cox stirred up a hornets’ nest by suggesting that we are alone in the Universe. It was a statement that seemingly contradicted the current cosmological orthodoxy that holds life is more likely to be abundant. Tyson, however, thinks his sparring partner was verballed.

“I don’t think Brian Cox meant that life on Earth is the only life in the galaxy,” he says. “What he surely meant was that we are the only *intelligent* life, as we’ve come to define it.”

Intelligent life on Earth, let alone in the rest of the Milky Way, is a rare phenomenon, he explains. If one regards the use of technology as the diagnostic factor, then, by self-serving definition, intelligent life is limited to only one species among millions.

02



An image of Jupiter’s moon Europa obtained by NASA’s Galileo mission suggests a warm interior lurks below an icy surface.

“And we’re just an accident,” he said. “We derived from a rodent-like creature scurrying underfoot of *T.rex*, 65 million years ago.”

Had an asteroid not smashed into the planet and caused the end-Cretaceous extinction event, then dinosaurs would still be roaming around and we’d be quivering in a burrow somewhere. On that measure, if not for that unlucky direct hit, intelligent life would *still* not exist on Earth.

“I think [Cox’s] scepticism about intelligent life has some basis,” he says. “But for life at all? No, I don’t see why the galaxy wouldn’t be teeming with it.”

NASA’s Europa Multiple Flyby Mission is set to

03



Neil deGrasse Tyson presenting the Fox-TV series *Cosmos: A Spacetime Odyssey*.

launch in 2025. When it reaches its destination, some six years later, it will buzz down as close as 25 kilometres from the surface of the moon. The resulting images might provide definitive evidence of life. Until then, however, the prospect of extraterrestrial biology remains empirically unsupported.

Indeed, many of cosmology's truly big ideas remain evidence-free positions. Concepts such as multiverses and multiverses arise from theoretical rigour, but proof remains elusive. Even the idea of how one might *recognise* such proof remains unknown. For Tyson, however, this is no reason to stop looking.

"You can assert in advance that these questions can never be answered, but how do you really know?" he says.

"When the Greeks proposed that there was a smallest unit of matter, indivisible, and called it an 'atom', they were imagining something that they could not yet measure.

"Later on, we would find ways to measure an atom, even though at the time the concept was proposed it was unimaginably small. And then we had an atom and we found out we can split it, and go even smaller."

In quantum mechanics as in cosmology, the more eyes that search for answers, the more likely it is that answers will be found. Tyson is heartened by continuing investment in space research, not just by the US, Europe and Russia, but increasingly by other nations. He cites Mexico, Canada, South Africa, India, China and Singapore as prime examples.

And as more and more nations turn to the night sky, perhaps, the more the unknowable will become simply the unknown.

"To have ideas that go beyond what you can experimentally reach at that time should not prevent you saying that just because today we cannot conduct that experiment we shouldn't therefore investigate it," he says.

"I think that would be short-sighted. To not study something, simply because today you can't demonstrate that it's there, prevents the full frontier of new ideas from guiding the next experiment – something that maybe no one has thought of yet.

"I take issue with the very idea that there could be something that can never be known, and never be tested. I haven't seen that in the very history of my field, so I'm not going to assume that it will exist in the future of my field."

So there. Thus sayeth the badass. ©

DR NEIL DEGRASSE TYSON visits Australia during August. 7 August, Melbourne, Plenary, MCEC; 16 August, Brisbane, The Courier-Mail Piazza, South Bank Parklands; 22 August, Sydney, Hordern Pavilion; 23 August, Canberra, Llewellyn Hall. Tickets available at thinkinc.org.au

ANDREW MASTERSON is an Australian science and culture writer. He is also a prize-winning crime novelist.

IMAGES

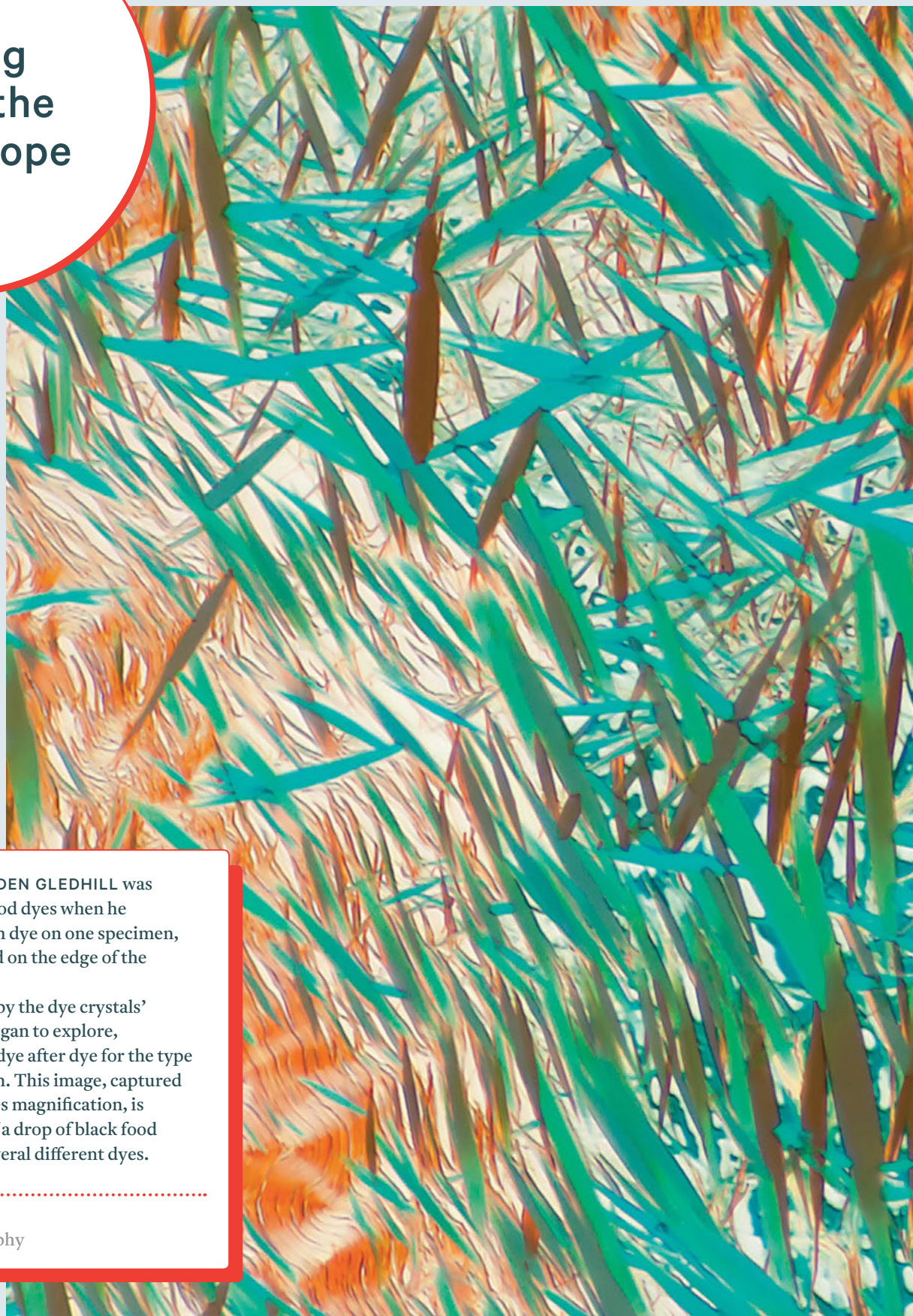
01 Miller Mobley / Redux / Headpress

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03 Fox / Getty Images

SNAPSHOT

Dyeing under the microscope



BIOCHEMIST-ARTIST LINDEN GLEDHILL was staining yeast cells with food dyes when he accidentally used too much dye on one specimen, and a tiny drop crystallised on the edge of the microscope slide.

Gledhill was so struck by the dye crystals' dramatic shapes that he began to explore, systematically examining dye after dye for the type of crystals they would form. This image, captured at approximately 100 times magnification, is the crystallised remains of a drop of black food colouring, a mixture of several different dyes.

IMAGE

Linden Gledhill Photography





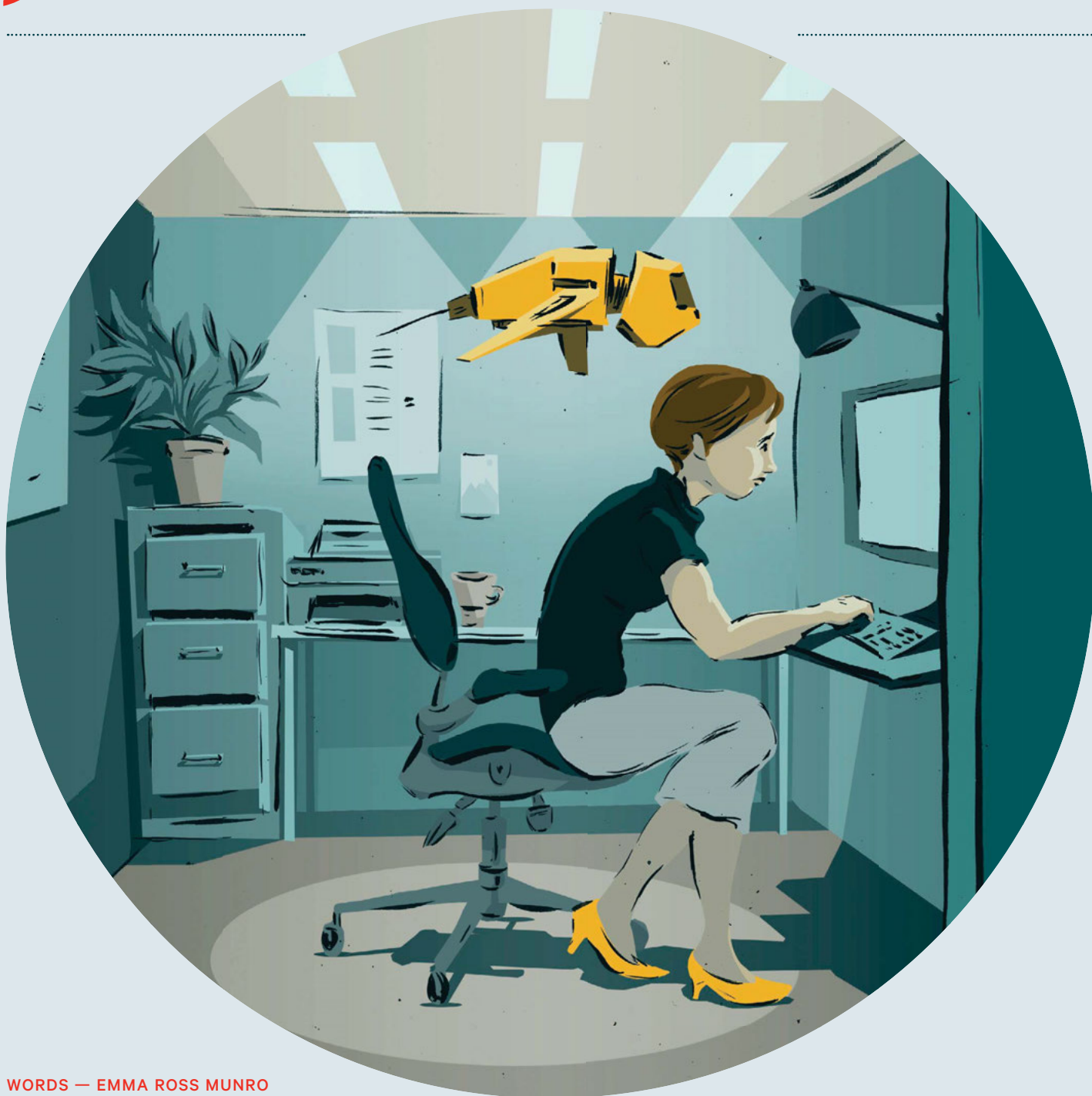
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SCIENCE FICTION

NUKE MY JOBBOT



WORDS — EMMA ROSS MUNRO
ILLUSTRATION — GATSBY

BECAUSE I'M AN OPTIMIST, I rotated my inspiration cube to read "Born Free" as Blair from Human Resources wheeled her trolley over. She handed me a vibrating box.

"Here we go, Melissa," she said. "Welcome to taking your work to the next level – to 110%."

"THAT'S WONDERFUL," I lied. "But I thought Data Acquisitions wasn't scheduled for tagging until next quarter?"

The spasms in Blair's fingers belied her botoxed serenity. I had momentarily dropped out of the corporate ecstasy required in this quadruple-dip recession, despite having signed the recontract with its mandated productivity upgrade.

The contents of the box – my very own biotech companion – was designed to make the upgrade possible. It was developed by Bioengineering Efficiency and Productivity Inc, a two-year-old pop-up, now ranked number three on the Global 100 Index. According to BEPi's label the innovation's two-fold objective involved evaluating an employee's 'enjoyment factor' whilst increasing their productivity – more like welcome to another round of inept managerial decisions and extreme micromanagement.

My workday consisted of inserting data into spreadsheets, and now I had to factor in the joy of an airborne pest keeping tabs on me.

Blair smirked. "Maybe you'd rather opt out?"

"Not at all." Not in a labour market with 1,600-plus people chasing every job. I flipped the lid and out popped my fist-sized, yellow-and-black bumblebee-striped buddy. "Oh, how exciting. Does it come with a manual?" And an 'off' button?

"Oh, you needn't bother reading the manual. Each jobbot is self-monitoring, self-reporting and self-adapting. That's what bioengineering means." She stretched out the word bioengineering as if I were an idiot.

"This thing is alive?"

Blair actually tittered and said: "Of course not, though they used some biological processes in its design. Don't worry about that stuff. Worry about the automatic reporting."

I sighed. Say hello to Big Brother. Blair tiptoed away on red stilettos. She repeated the 110% sales pitch 24 times before teetering into the lift with an empty trolley.

My jobbot buzzed over my workstation like a bee scouting for pollen. A busy bee swooping from my paper stacks to my alphabetised folders to my blank computer screen, possibly assessing my readiness to start working. Five seconds later, my new buddy dashed to the computer's on/off button, and then to the bridge of my nose, and then back to the computer screen. It repeated this noisy dance until I realised it would not let me sip my latte while I gradually joined the rest of the wide-awake world.

Two gulps finished the coffee. From the depths of my bag I grabbed a vial of ginseng and an electrolyte shot, both of which I poured down my throat as if it were month-end reconciliation. While the desktop warmed up, I sorted reports into urgent versus never-mind piles and tapped my toes to the combined thrum of caffeine and sugar. Within seconds, my fingers flew across the keyboard.

As fast as I typed, the jobbot hit the delete key. Multiple error messages flashed. In the corner of my screen, technical support opened a chat window: did I need help? That had to be the fastest response ever. Normal response time could be two days. With the jobbot hovering above my knuckles, I declined their assistance with shaking fingers. The little bugger objected to gibberish being entered into the database. If it could read and use a keyboard, what did the bosses need me for?

At elevenish, I uncranked my spine, cracked my knuckles and stood for my midmorning OH&S-mandated stroll. Normally I took full advantage of the open-space design, chit-chatting my way to the water cooler so I could discover whose core competency rating had fallen foul of Human Resources' SWAT team. Not this day. After a couple of backbends and wrist extensor exercises, the jobbot headbutted me back to my desk.

At midday, a desperate dodgem race got me through the washroom door. The pest followed me into the toilet cubicle where the fine print on the recontract had said it was not supposed to go. Joy factor: zero.

At lunchtime, jobbots swarmed to block the lift. Like trained rabbits, we sat back down at our desks. My jobbot slowed and landed, only to crawl all over my homemade sushi rolls. I leaned back and peered around the partition between our workstations.

“Hey, bestie, you still a go for liquid therapy tonight?”

“Sure. We’ll have earned a Long Island tea by then.”

Carey’s jobbot circled her whole-wheat pasta salad before pushing the jam-filled donut into the trash bin. Nutrition monitoring was not in the recontract either. Carey, who looked like a marathon runner but wasn’t, muttered, “Never mind, I’ve got a boxful at home.”

I tore at a piece of chewy seaweed and wished for the pint of Ben & Jerry’s in my freezer, while mentally listing my feedback on this efficiency monster. The X-rated version got me grinning.

I swallowed the last mouthful of rice to find the jobbot revving up to full buzzing volume. It zoomed between screen and keyboard in a figure-eight dance, once, twice and then so fast I could barely see it. As if hypnotised, I found myself sitting up straight and typing.

That first jobbot day, all 25 of us stayed at work an extra hour until, fingers stinging and backs aching, we trudged outside, which is when we discovered the bloody little monsters *could* leave the building.

“Bollocks,” Drew said, eyeing his monster in an evil-scientist way, “it is *not* coming home with me.”

“How are you going to stop it?” Mine spun overhead like a demented halo as Carey, Drew and I plodded up the metal stairs to our suburban train platform.

“I’ll figure something out. Watch this space.”

I didn’t share Drew’s confidence but I admired his determination. I checked my watch. If the train was on time, I’d be home, in slippers and nestled on the couch in 20 minutes. We shuffled forward to join the hundreds of queuing commuters. About half had jobbots of their own. As the train approached, our jobbots lowered to waist height and proceeded to whip around, corralling the three of us on the platform. Like sheep.

SHE REPEATED THE 110% SALES PITCH 24 TIMES BEFORE TEETERING INTO THE LIFT WITH AN EMPTY TROLLEY.

Blair appeared, jobbot-free, skirted around us and dashed between the closing doors. We gave her retreating backside the collective finger. Our jobbots slowed to cruising speed and zipped out of swatting reach of my handbag and Drew’s cap.

“Double bollocks,” Drew said. “Hello to the optional 24-7 monitoring clause, to be applied at the whim of management, but apparently not *to* management.”

“Blair wouldn’t do that to us. It has to have been upper management,” Carey said, busily texting her girlfriend that she’d missed the train. Because I’m such an optimist I hailed a cab, but wasn’t surprised at the jobbots extending their bee-like stingers when it pulled over.

Drew kicked the curb. “Wanna bet there’s a clause in the fine print about daily exercise?”

“Maybe this is a technical glitch? We could try calling tech support.” Carey was already searching her phone. Five minutes later, she found the single option of contact via email, through which we could request assistance, but the 48-hour guaranteed response was a little useless – and not at all surprising.

AS THE TRAIN APPROACHED, OUR JOBBOTS LOWERED TO WAIST HEIGHT AND PROCEEDED TO WHIP AROUND, CORRALLING THE THREE OF US ON THE PLATFORM. LIKE SHEEP.

“Plan B?” by which Carey meant the nearest bar instead of our favourite one two blocks from home. We lived in the same apartment complex.

“Sure.” I liked Carey’s go-with-the-flow life mantra – so dependable. But I hadn’t bought my shoes with an hour’s trek over concrete in mind. Wanna bet the jobbot wouldn’t pierce my blisters?

“I’m sure we’ll find plenty of booze specials to numb us along the way.”

After a few minutes of Carey Googling the safest route with a happy-hour bar, we plunged into the crowd of workers trudging home. Hundreds, if not thousands of jobbots buzzed overhead, drowning out the traffic, something I’d thought impossible. Close by, two cops and their armoured jobbots herded a family of street people back into a side alley of dumpster homes.

Carey shook her head. “That’s the alternative, isn’t it? Jobless and living in garbage.”

“They’re losers,” Drew said.

“Oh, you know their life stories, do you?” Though I disagreed with Drew, their ratty clothing, unkempt hair and hungry eyes were my worst nightmare. Head down, handbag clutched tight, I didn’t look back down the alley.

Soon enough, we found a happy-hour bar. Two bouncers with bats stood on either side of the doorway.

They nodded in a friendly way. “Duck,” the biggest one said.

He swung his bat and cracked my jobbot all the way across the four-lane highway. For the first time in my life, I whooped like a cheerleader. Drew and Carey’s jobbots belted past. Drew hooted and Carey videoed.

“Quick, get inside. We’ll keep them busy. Enjoy

yourselves.” The bouncers swung into action as the jobbots hurtled back, stingers extended.

We stayed until closing. That night it was leather lounges, live music, dry martinis, mojitos, pints of lager, mixed olives, Yukon gold potato fries. Topped off with fudge brownies at 2am smothered in hazelnut ice-cream at my place.

At dawn my head bounced against the bedside table. The jobbot dive-bombed again and I crash-landed on the floor. I spat out carpet fluff and reached under the bed for the cricket bat. Lurching upright, I chased the jobbot, but it moved faster than I could at that time of day, or any time of day, for that matter.

Black coffee and a green juice later I emptied the hall closet until I found my ex’s water pistol, air rifle, dart gun and butterfly net. I loaded them all and devoted the entire weekend to shooting, drowning and netting.

Nothing succeeded in slowing the jobbot down, let alone stopping it.

A MONTH LATER BLAIR, upgraded to HR supervisor, called a meeting to assess our productivity. Her predecessor had dropped dead over the weekend (surely a jobbot-induced heart attack). As soon as we were seated, Blair’s beach-ball-sized jobbot proved irresistible to our comparatively teeny jobbots, which darted over and stuck like gnats to honeycomb, making the meeting the best thing that’d happened at work since the upgrades had arrived.

I DISCOVERED THAT ONE CANNOT ACTUALLY DIE OF EMBARRASSMENT, BUT ONE CAN DECIDE TO INFLICT APPROPRIATE PAYBACK.

Blair opened the session and thanked us all for the detailed feedback on our jobbot experiences. Many people had apparently accessed the email contact option.

“Human Resources is pleased to report that Data Acquisitions increased productivity by 39% in only one week.

“Congratulations! We eagerly anticipate your increasing efficiency ...”

My personal productivity had zoomed up by 49%. I would have done naked handstands before openly acknowledging this benefit. Maybe jobbots weren’t the end of civilised work, but, as far as any water-cooler gossip might know, I stood firmly in Drew’s rebellion camp.

Even so, while Blair droned on about micromanagement practices, e-recordings and outmoded surveillance devices, I imagined retiring early, living off-grid and becoming a pastry chef who didn’t care if her hip dimensions doubled.

Blair’s jobbot jabbed its hairy proboscis into a socket. The wall of screens behind her flickered.

Each screen showed a different person.

There was Carey, stung to typing at finger-blurring speed. Sammy, flossing at her desk, jobbot zeroing in for a close-up shot. And Drew, chicken dancing after making his computer display a fake technical error, until the jobbot stung his jiggling posterior (he was still unable to sit down). All 25 of us watched in rabbit-struck horror, or twittery hysterics, as our lives for the past week played fast-forward on the screens.

And there I was gasping on the cross-trainer with the jobbot vibrating until it spun apart to form a pellet swarm of the word ‘FASTER’ in front of my face. Oh no ... there ... in the privacy of my home ... about to bite into my last, much-cherished, though slightly stale, Belgian chocolate, caramel-centred brownie. Then, there I was with my tongue jobbot-stung to an obscene size. I rubbed my aching knuckles, a new habit I’d acquired since the arrival of my little friend, and grabbed my inspiration cube. Under cover of the table I speed-pivoted the six faces, mixing the letters to read “This Means War”. Drew, sitting beside me, nodded. Carey blanched and looked away.

Over squeals, gasps and giggles, Blair preached about the development of a superior workforce, core competencies and empowerment through ongoing personal growth. I discovered that one cannot actually die of embarrassment, but one can decide to inflict appropriate payback. Say goodbye to acceptance and optimism. Say hello to grievous jobbot harm. Or Blair harm. I could pierce her implants with scissors and switch her Botox for correction fluid. Or I could get another job, which would be far less messy than skewering her boobs.

ANOTHER JOB SEEMED LESS and less likely as weeks passed without a single interview, despite a hefty pile of applications. I could not – would not – end up like Drew, who was now living in a tent on my balcony. Drew had been fired after crashing the office network.

My jobbot never went on standby or ran out of power. There was no ‘off’ button. My jobbot didn’t show any interest in shopping, art gazing, theatre or knitting. It found bees intriguing, though, which I discovered on a distraction-seeking expedition to the zoo. Three hives now crowded Drew out on my balcony.

Most evenings, while the jobbot watched the bees, I ate chocolate fudge ice-cream, researched bees and sent out imaginative job applications. To reward my job searching, I’d sedate the jobbot with a bee smoker, then nuke it in the microwave while it was helpless.

Drew taught me the nuking trick. An ex-chemistry teacher, he’d figured out several ways to exterminate jobbots for cash or beer. His favourite kill involved



flowers, ovens and dancing *The Time Warp* while the jobbot melted, despite knowing he'd get stung when the replacement arrived. Replacements always turned up, even after an employment agency blew up the original BEPi headquarters, because a jobbot swarm set up a hive on the bombed-out site. Pretty soon jobbot hives appeared in every city worldwide. The synthetic biologists had outperformed their own expectations. The jobbots bred like ... well ... like bees. What's more, they evolved with each new generation: bulletproof carapaces, sharper stingers, larger — much larger — neural networks.

Coward that I was, I only started nuking once the jobbots stopped retaliating. Perhaps breeding prolifically meant each hive didn't mind occasional losses. Or, more likely, payback — such as Drew's repeatedly punctured butt — lowered productivity.

Nuking them was terribly satisfying, although each exploded jobbot was only a tiny victory, a focus for my fury towards the Blairs and CEOs who had introduced the jobbots in the first place.

Those jobbots had apparently become independent of human intervention — and that scared me.

MANY MONTHS LATER, while we were warming up on parallel treadmills, Carey admitted she adored her jobbot. "I fit in my skinniest jeans, have a teenager's heart rate and a new girlfriend. What's not to like?"

Her pretty metallic green jobbot seemed to be in original condition, too — no nuking or dismembering for Carey. Love? Co-dependence was more likely. She couldn't wait for it to weed the pot plants, balance her bank statements and dash to the store for diet cola.

As much as I hated my jobbot, I hated Blair even more for exposing our private lives, our secret vices. "So, what's happened to Blair?" I said. "She's gotten rather blowsy instead of liposucked skinny. I thought she'd had all her fat cells sucked out once and for all."

**"JOBOTS ARE THE BEST THING
TO HAVE HAPPENED TO US.
OPEN YOUR EYES."**

"Oh, give her a break, Mel. It's a little stress eating. Two job promotions in three months is a lot to take on."

"One predecessor died of a stroke and the other from a heart attack. Management is turning us into worker drones. Like bees, which die on the job too." My jobbot bustled in and hovered over the speed arrow. I pressed the appropriate button and picked up my pace.

Carey slammed her hand on the handlebar and actually frowned at me. "Jobbots are the best thing to have happened to us. Open your eyes." She waved her arms around. "The gym is packed. Hospital admissions are



down. Crime is down. Employment numbers are steady. The global economy is bouncing. The NASDAQ, the FTSE and the Dow Jones have hit their highest peak since the birth of the euro. How can you object to any of that?"

Somehow Carey did not seem to comprehend that people were too scared to quit. I trembled at the thought of food stamps and showering at the YMCA.

"Oh yeah, life is good on Planet Jobbot if you don't mind being a drone at the beck and call of a fat queen."

"You are in serious danger of becoming fattist."

Carey examined the treadmill program, selected cardio challenge and ran.

That shut me up. Carey had converted to jobbotism, a brand new term. My speed interval program kicked in, and I heaved in air damp with sweat, deodorant and perfume. I pounded the treadmill belt and imagined Blair stretched out on it, being pummelled with each footfall. Thanks to her, my co-workaholics and I were regularly exposed to ridicule, but not Blair. Her fat jobbot must have recordings of Blair, but how could I access and circulate them?

I knew where she lived.

THAT NIGHT, DREW AND I were squatting in a buckthorn bush arguing about how to break into Blair's townhouse when a swarm of jobbots hurtled to within a hair's breadth of my nose. We crawled out of the bush and very slowly

backed away. The jobbots hovered until we turned the street corner.

Back home, we downed tequila shots and invented Plan B. Drew peeled open a jobbot and inserted a miniature spy device that streamed to the internet, as a test run for Blair's jobbot. Within three seconds the jobbot ejected it in a foul stream of bot-poop on my shag pile carpet.

Time to come up with a Plan C.

WORD MUST HAVE GOT AROUND that I was searching for another job, because Human Resources granted me an optimising placement evaluation – whatever that meant. Any offer would be irresistible if it meant getting away from Blair's micro-monitoring.

A hefty mortgage, student loans and a weakness for plush lounges and air-conditioning meant I was a marshmallow who wouldn't risk a written reprimand, let alone five minutes between jobs.

Yet I risked everything with Plan C. Possibly, I'd become ever so slightly obsessive-compulsive about Blair, a side effect of not having had a moment's peace and quiet since the jobbot's arrival. I had downloaded the appropriate Trojan software and loaded it onto a USB. All I had to do was stick it in Blair's computer during the placement evaluation with a little help from my trusty bee smoker.





Blair's office sent a reminder for the appointment. I saved, stood and squeezed past the back of Carey's chair. The office layout had changed from open plan to a 'focused collaborative workspace' or hexagonal hive-hell. A vending machine had replaced the water cooler.

OK, yes, regarding the upcoming interview, thanks were due to my buzzy-buddy, I had to admit – I'd aced every performance review. And yes, my imagination extended to sneaking a peek at Carey's performance responses and upgrading my own a notch or two. As far as Blair knew, I was a willing cog in the greater honey-making machine.

Honeybees were now my favourite topic of conversation and research. I preached jobbotism ... loudly. Wasn't it grand how babies and children now had buzzy robot companions to count down their sleep, play and study periods? Don't forget the lucky retirees with nannybots to make sure they finished all their pureed broccoli.

THE OFFICE LAYOUT HAD CHANGED FROM OPEN PLAN TO A 'FOCUSED COLLABORATIVE WORKSPACE' OR HEXAGONAL HIVE-HELL

In the honey-toned corridor outside Blair's office, I mopped sweat from my upper lip. The possible consequences of Plan C, such as permanent unemployment, dumpster living and probably dying on the streets, held no appeal. Of course, I could leave the bee smoker and smoke grenade in my pocket.

Plan C depended on the jobbots emulating bee biology and behaviour, as seemed to be the case with my own jobbot. The smoke grenade would crowd the drones around their queen to protect her, maybe give Blair a little trouble breathing – it would possibly suffocate her. In the confusion I would plug the USB stick into her desktop computer, which would automatically install the backdoor Trojan and stream Blair's videos straight to the Vimeo account I had set up.

One of her minions opened a door and ushered me inside. Blair pretty much lived in the office, along with her aerodynamically challenged jobbot. Her office, wallpapered in wildflowers, smelled of springtime blooms. Blair sprawled behind a rosewood desk piled with printouts, pots of honey and – of course – her jobbot.

"Welcome, Melissa." Blair pointed me to a seat and offered me lemon and ginger tea. I accepted. "Would you like a dollop of honey?"

"Yes, thank you."

An intern jumped up attentively and did the honours.

"Melissa, do you think jobbots, as similar as they are to bees, remind us to extract the honey out of life?"

Gobsmacked, I shut my mouth.

"What I'm wondering is, are you doing all you can to make your life more productive?"

"Ahh ..."

"Always remember that the bee is the symbol of accomplishing the impossible, which brings me to why I asked you to come today. I'm impressed at how well you've adjusted to the jobbots." Blair smiled at her flightless companion. "So, I'm pleased to inform you that you've been admitted to our career-enhancement program."

Whatever that meant. "Thank you so much." I hid trembling fingers in my pocket next to Drew's homemade smoke grenade. Blair looked pale and tired. Perhaps she didn't deserve suffocation after all.

"In fact, if you're interested, you could strategically upsize immediately."

I still didn't have a clue what she meant but I needed to keep her talking. "Yes, I'm very interested. Thank you." Images of Drew flashed before my eyes: sleeping on my balcony, obsessing about jobbot extermination, forgetting to wash, drinking too much beer. Did I truly want to risk my job and my home to settle this score?

Blair smirked, just like she had at the last mortifying Monday session. Enraged, I tugged the bee smoker and the small canister out of my pocket and stroked the grenade pin. She deserved it, all right.

"Excellent." Blair tapped her computer screen, which beeped and flashed acknowledgement. She smiled. "Your verbal acceptance is recorded and verified. Your new position will take effect immediately. Congratulations on your appointment to Human Resources. You'll start with the monitoring job I had, and one day you'll be right where I am."

Right where Blair was ... *oh, crap.*

But ... I *needed* my recliner, my film noir collection, and *all* my books. And, I'd damn well earned that Ben & Jerry's ice-cream cake waiting for me in my air-conditioned apartment. Blair's job had many tempting perks: such as jobbot-free time. Drew's life as a corporate revolutionary wasn't an option for me. Score yet another round to Blair.

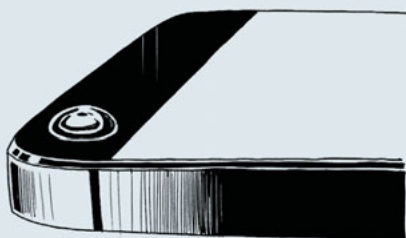
I slipped the grenade and bee smoker back into my pocket. As I passed my desk on the way out, I reconfigured my inspiration cube to read "Born to Survive". ☺

EMMA ROSS MUNRO lives in the Blue Mountains, and has had fiction published in *Every Day Fiction*, *Skin to Skin* and *Pure Slush*, among others. Currently she is a reader for *Daily Science Fiction*.

GADGETS AND GIZMOS

The mobile laboratory

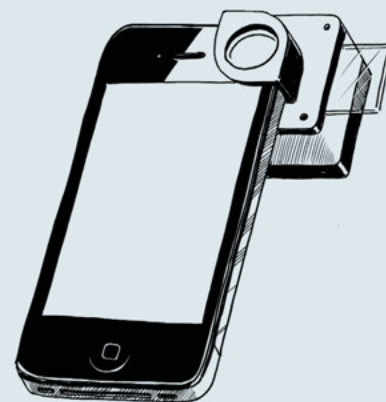
THE SMARTPHONE IN YOUR POCKET connects you to the world wherever you stand. The potential of this tiny powerful computer extends way beyond sharing cat videos – your mobile phone can go where sophisticated lab equipment can't. Engineers have developed nimble devices that hijack your phone's imaging and computing power, and are set to revolutionise medical diagnostics. They're rolling out to healthcare workers in developing countries, primary school classrooms and your family home. We bring you up to date with mobile phone clip-ons that bring the laboratory to your pocket with the swipe of a finger.



1

DROPLET LENS

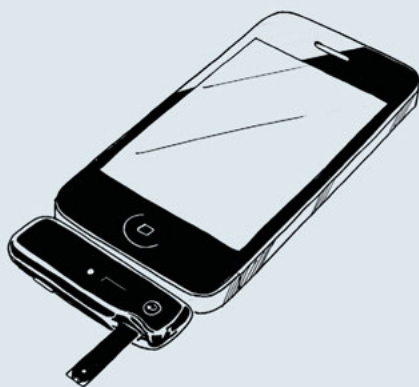
Set to transform the science classroom, these 50 cent lenses attach to smartphone cameras, converting them to microscopes that magnify up to 100 times. Future applications include detection of skin cancer and analysis of diseased crops. And you can make them – all you need is some elastomer, a 3D-printed plastic cartridge, an oven and 20 minutes. A kickstarter campaign for the “DIY lens maker” was launched by Stephen Lee’s team at the Australian National University in July.



2

D3 (DIGITAL DIFFRACTION DIAGNOSIS) SYSTEM

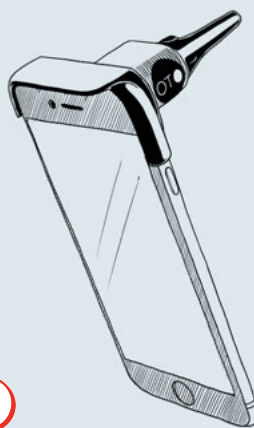
Developed by Massachusetts General Hospital scientists, this gadget will broaden cancer screening in limited resource regions. The imaging module has an LED light that shines through a blood or tissue sample mixed with specially designed microbeads that can detect cancer-related molecules. At just \$1.80 per test, pilot tests identified abnormal PAP smears, lymphoma markers and human papilloma virus DNA.



3

IBGSTAR

This small, sleek device turns your iPhone or iPad into a blood glucose meter. Prick your finger with a lancet, draw blood into the electrochemical sensor through a test strip and up pop blood glucose levels. The device comes with an iOS app for “real-time” tracking: type in meals, exercise and changes to insulin injections and send combined data to doctors to devise better diabetes management plans. It can be used on its own without a phone and has been available in Australia since 2012.



4

OTO HOME

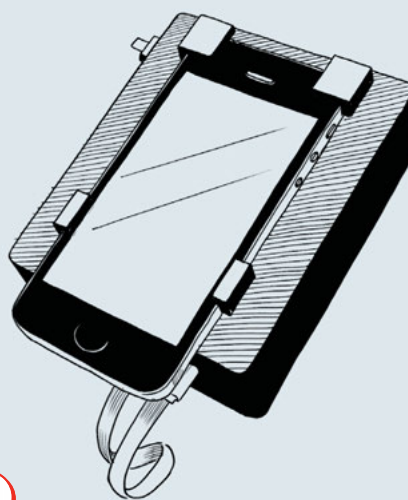
Kids often get ear infections but also hate going to the doctor. This prompted San Francisco-based medical tech company CellScope to develop the Oto HOME – a clip-on conical optical device for iPhones that turns a phone’s camera into an otoscope. A short video of an afflicted eardrum is sent to an on-call paediatrician. Within two hours, you get a response that includes a diagnosis and treatment plan minus the waiting room. The device is available in California.



5

UMED

uMED costs \$25 and runs on any low-tech phone. It is an electrochemical reader designed to test for environmental pollutants, measure blood glucose levels and detect malaria. Insert a sample strip containing blood, urine or water, select the test and hit “go”. The device then sends results to physicians or researchers tracking disease outbreaks. uMED’s software converts data to audible tones that can be transmitted over the voice channel of any mobile network.



6

LOA

This CellScope device diagnoses the parasitic Loa Loa eye worm – a potentially lethal co-infection for recipients of certain parasite drug treatments in Africa. Smartphones snap on to the device and gears on a 3D-printed plastic base shuttle blood samples along the phone’s camera, recording video. An algorithm then analyses them for worm wriggles. In a pilot study the Loa quantified worm levels within three minutes.

— VIVIANE RICHTER

ILLUSTRATIONS
Jeffrey Phillips

REVIEWS

Marie Curie and the gender card



IN THE OPENING CHAPTERS of this book we read scraps of evidence that posit Marie Curie as the best-known female scientist of our time. Whether she is or not is almost irrelevant to this discussion; that we must distinguish her as a female scientist is what is paramount here.

Inescapably and intentionally *Making Marie Curie* captures more about gender roles in Europe at the turn of the century than it does about the life and times of the physicist who discovered radium.

The book's author, Eva Hemmungs Wirtén, a professor of mediated culture in Sweden, intersects Marie Curie's life story with discussions of intellectual property and celebrity culture, as well as the mainstream media's bad habits.

The discovery of radium is credited to Marie Curie and her husband, Pierre, and it wasn't a quiet affair. Further insight into X-ray technology captured the public's attention, as did the husband-wife laboratory team.

Marie and Pierre refused to patent their discovery, preferring to leave open the door to further research and development. Hemmungs Wirtén carefully reminds us that at that time married women were not considered citizens: according to French law, they could hold no property, and therefore no intellectual property.

The implication is that Curie's rewards after her discovery were greater due to the lack of a patent, particularly after her husband's unexpected death in 1906.

Marie Curie did benefit, in a sense, from her celebrity status. In 1903, she became the first woman to win a Nobel Prize. That the public was entranced by this revolutionary scientist is not surprising, nor is her rise to international superstardom. But as we know, with any great media frenzy comes scandal, and the media salivated over Curie's affair with Paul Langevin, a married man and former student of the late Pierre.

The way the saga played out is familiar and abhorrent: the battle between newspapers for private details of Marie's life; the public tit-for-tat between the players in the drama; and Curie's hounding by the 1900s equivalent of the paparazzi.

Yes, there are some disturbing similarities between then and now, but also some glaring differences. In France at this time it was customary for men to challenge one another to armed duels if they felt their honour was in question. This was a more direct solution to cases of defamation and the like, and much faster than waiting for a court decision. Hemmungs Wirtén cites five duels that resulted from the media frenzy over Curie's romance. (The author tells us the duels are available to watch on YouTube: by no means graphic, the silent shorts are worth a look for context and comic value.)

Marie Curie also had some powerful friends behind the scenes. Albert Einstein was her champion and occasional confidante ("Like no other scientists at the time, both knew how heavy — and how rewarding — the burden of celebrity could be," writes Hemmungs Wirtén).

Another beneficial friend, US journalist Missy Brown Meloney, was responsible for a campaign that raised \$100,000 in cash donations from the women of America to purchase one gram of radium as a gift to Marie Curie — a 1900s version a crowd-funding campaign. While in the US, however, we're told Marie Curie was subjected to criticism for her "black-dressed and haggard looks" in a country "where celebrity culture depended on celebrities' willingness to play along" — another social standard that rings true today.

THAT THE PUBLIC WAS
ENTRANCED BY THIS
REVOLUTIONARY SCIENTIST
IS NOT SURPRISING ...

Making Marie Curie is an academic read, but its most engaging aspects are the reflections on the tabloid press and the conflicting outcomes of public life. The efforts taken by a powerful woman to retain her status, only adds to the legend that surrounds Marie Curie — one of the best known scientists, gender not specified, of our time.

— AMY MIDDLETON

NON-FICTION

Making Marie Curie: Intellectual property and celebrity culture in an age of Information by EVA HEMMUNGS WIRTÉN

The University of Chicago Press (2015)



NON-FICTION

Soviet space mythologies: Public images, private memories, and the making of a cultural identity by SLAVA GEROVITCH

University of Pittsburgh Press (2015)

SLAVA GEROVITCH IS A LECTURER in the history of mathematics at the Massachusetts Institute of Technology. He has written extensively about the history of the Soviet space program and other scientific achievements of the country, often with an unexpected perspective.

In his first book, *Cyberspeak: A History of Soviet Cybernetics*, he argued that Soviet cybernetics was not only an intellectual trend but a social movement for radical reform. The book was hailed by Western critics for its insights into the history of scientific thinking in both the Soviet Union and the United States. The main Russian philosophical journal, by contrast, was scathing. *Soviet Space Mythologies* is likely to please them even less.

Gerovitch argues that the Soviet human space program was torn between two narratives – one that favoured the cosmonauts as heroes of the new age, and the competing account of the space engineers in which the cosmonauts owed everything to ground-based scientists.

Official propaganda, meanwhile, often sought to equate the space program with the communism project, a viewpoint that tended to favour the cosmonaut and his role as “New Soviet Man”. But in this, the propaganda machine harked back to more traditional communist themes, which, Gerovitch says, “subtly undermined the futuristic message”.

Gerovitch also points out that rewriting history is not only a Soviet failing. He refers to a study run by cognitive psychologist Ulric Neisser from 1986-88. In that, 44 subjects were asked to recall how they first heard of the Challenger space shuttle disaster. They were asked the morning after the event and then again 30 months later. None of the later accounts tallied with the original statements.

The book closes by looking at the legacy of the period on Russia today, where the space program provides a history that all Russians can be proud of.

“In post-Soviet Russia the cultural heritage of the decades of the communist rule oddly mixes with the newly developing capitalist culture,” he writes, combining old Soviet symbolism with “new Russian” capitalist values.

The book is a fascinating history of the Soviet space program and its public face. But it is much more than that. Undoubtedly it will be even more valuable as a resource for historians to understand how myths, propaganda and faulty recollection can come to write a collective memory that, however unreliable, becomes the framework for both the present and the future.

— BILL CONDIE

Science on song



MUSIC

Scientifica: Music meets science

Monash University Melbourne, Australia
scientificamusic.com

WHILE MUSIC HAS STRONG LINKS to mathematics, we seldom associate it closely with science.

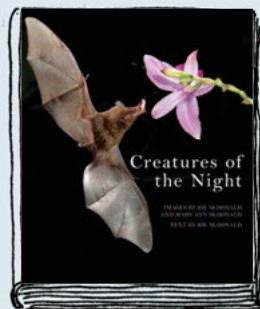
But Mary Finsterer, the Chamber Music Australia Chairwoman of Composition at the Sir Zelman Cowen School of Music, Monash University, and Christian Behrenbruch, a Vice-Chancellor’s Professorial Fellow at the university and a “serial entrepreneur”, are seeking to change that.

Through their Scientifica project they set out to find a fresh approach to drive interest in science education and decided to let music do the talking with three compositions (so far) inspired by science – *Star Song*, *Earth* and *MRI*.

“We decided to think outside the box and create a project that ignites our imagination and sense of wonder for the world around us,” they write.

The results are, at times, hauntingly beautiful and evocative. As Finsterer and Behrenbruch write: “Science is awesome, music is pure magic – together they can inspire.”

— BILL CONDIE



NON-FICTION

Creatures of the night
by JOE McDONALD and
MARY ANN McDONALD

New Holland (2015)

AND WHAT BEAUTIFUL CREATURES they are — the bats, the foxes and wolves, the big cats and other mammals that come out to hunt and feed while the rest of the world sleeps.

This is a comprehensive, beautifully photographed guide to the world after dark, including the nightlife of reptiles and amphibians, birds and even invertebrates.

Then, as a bonus, the final chapter is an excellent guide to how you might tackle the complicated task of taking your own wildlife pictures at night.

— BILL CONDIE

CREATURES OF THE NIGHT



LEFT

Indian Flying Fox
Pteropus giganteus

Fruit- and nectar-feeding bats are found throughout the tropics, and some grow quite large, with metre-wide wingspans. Fruit bats worldwide are essential for pollination and the dispersal of seeds, but most species are declining and some are in danger of extinction. Because of their prominent eyes and dog-like features, some species of fruit bats are known as flying foxes. Unlike most bats, which rely on echolocation, these fruit bats locate their food by sight or smell.

OPPOSITE

Pallid Bat
Antrozous pallidus

Most insectivorous bats catch their prey while in flight, snaring a moth or mosquito with their wings or net, but Pallid Bats hunt on the ground, locating their prey via echolocation, hearing and sight. Scorpions and ground-dwelling beetles and crickets are their favourite prey, but they will also catch nocturnal lizards and even small rodents.

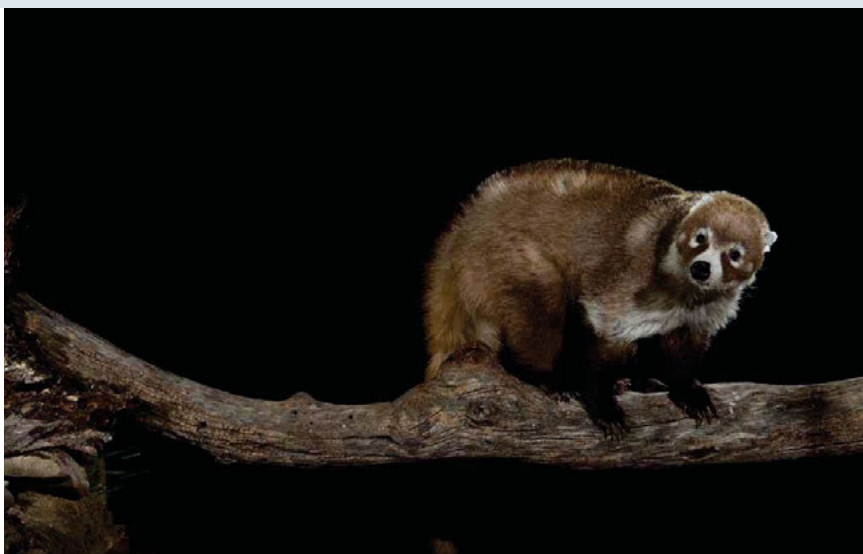
10



CREATURES OF THE NIGHT

RIGHT
White-nosed Coati
Nasua narica

Ranging from southern Arizona south through much of South America, the White-nosed Coati often travels in a family group that may consist of up to 10 members. Catimonde, as they're often called, will forage in a wide forest across the forest floor or upwards, consuming anything edible. They are equally at home on the ground or in trees, but when alarmed will drop from a tree and run to safety.

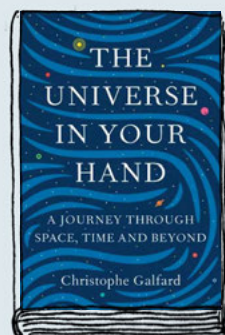


CREATURES OF THE NIGHT

RIGHT
Six-banded Armadillo
Euphratus sexcinctus

Looking like some type of turtle, the Six-banded Armadillo is one of 10 species of this unusual mammal group found from the southern United States to the tip of South America. All are burrowers possessing sturdy forelimbs equipped with thick claws, allowing an armadillo to dig quickly and disappear into soil or leaf-litter in seconds. The body armour appears to be a solid shell but it is not. Instead it is composed of separate bony plates, fused around the shoulders and hips to a hard shell but with a row of flexible bands in the middle in most species. This feature allows some armadillos to roll into a tight round ball whenever danger threatens.





NON-FICTION

The Universe in your hand: A journey through space, time and beyond by CHRISTOPHE GALFARD

Macmillan (2015)

NO ONE COULD ACCUSE Christophe Galfard of being unambitious. In this marvellous handbook to the cosmos, he tackles all the big ideas – quantum mechanics, general relativity, string theory and parallel realities – seeking to explain them to a lay audience. For those prepared to provide a reasonable level of concentration, he mostly succeeds.

If anyone could do it, one suspects Galfard's the man. He holds a PhD in theoretical physics from Cambridge University where he was Stephen Hawking's graduate student from 2000 to 2006. Of course, knowing your subject is no guarantee that you can communicate it clearly. But Galfard is the co-author of the children's primer on physics he wrote with Lucy Hawking, Stephen's daughter, called *George's Secret Key to the Universe*.

This offering perhaps benefits from that experience. While the writing is clear and direct it does not talk down to the reader. He begins with a promise – that he will try not to leave anyone behind. His book contains one equation, $E=mc^2$.

Throughout, Galfard's sense of wonder at the scale and beauty of the Universe shines through.

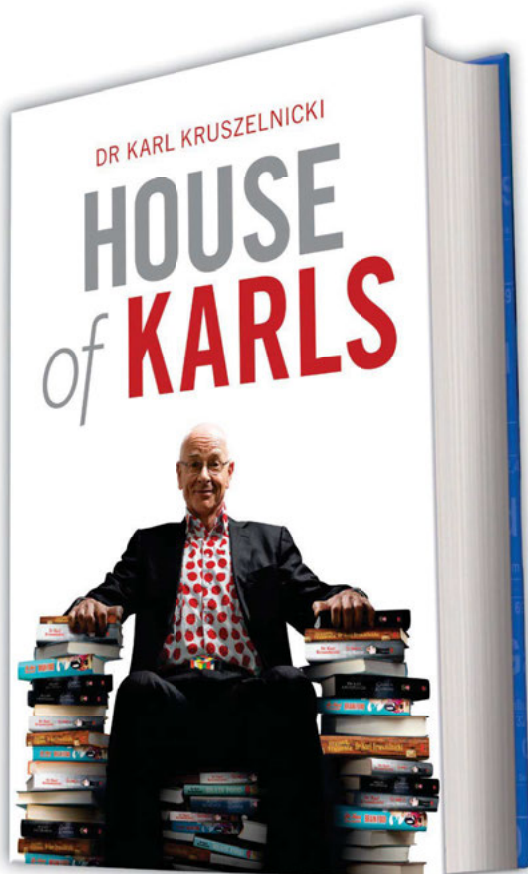
He describes his work as a series of *Gedanken* experiments – exercises in pure thought and the techniques used by philosophers and theoretical physicists throughout history to project themselves into places and situations where they cannot physically travel.

In this way we visit the surface of our Sun in its death throes, experience the grip of a black hole, the spooky surface of an alien planet lit by twin stars and, perhaps the oddest place of all, the quantum universe of the very, very tiny.

Galfard acknowledges the risks in this approach.

"Some of what we have learnt throughout this journey may turn out to be wrong ... Dark matter, dark energy, parallel worlds and realities are all ideas that may eventually be abandoned, but they are the most powerful ideas of our time, nonetheless," he writes.

— BILL CONDIE



DR. KARL KRUSZELNICKI

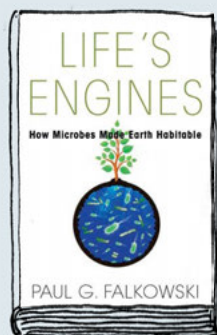
HOUSE

of KARLS

KNOWLEDGE IS POWER



MACMILLAN
Pan Macmillan Australia



NON-FICTION

Life's engines:

How microbes made

Earth habitable

by PAUL G. FALKOWSKI

Princeton University
Press (2015)

LONG BEFORE THERE WERE HUMANS – or dinosaurs, or plants – there were the microbes. In fact, as Paul Falkowski reminds us, for almost four billion years, microbes had the Earth to themselves, busily transforming the chemistry that would pave the way for the arrival of all living things.

Falkowski brings a formidable breadth of scientific understanding to the task of explaining this, having worked as a biologist, an oceanographer and an astrobiologist. He moves easily between biological and earth sciences to help us understand the steps microscopic single-celled organisms took to make the planet habitable.

But clearly his first and greatest love is, as he describes it, “getting under the hood” to work out what makes the machinery inside living cells work. He says this is somewhat analogous to trying to understand what makes a car function if you start with no notion of the internal combustion engine, adding “cells are a lot more complicated than cars”.

And in that complexity lies the explanation of how we, and all living organisms, are here today.

Falkowski likens the driving force of a cell to a nanomachine and describes how cells and their nanomachine engines have been assembled from the simple to the complex in all animals and plants. In this way, he explains, we are all the sum total of the microbes that made us.

His book is also a fine lesson in the history of

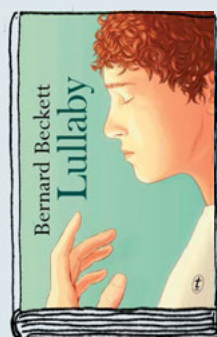
science, taking us through the discoveries that have given us insights, if not a complete understanding, of the basic building blocks of life.

As has become almost mandatory in any discussion of evolution, *Life's Engines* comes with a warning. Falkowski believes microbes have the power to cope with change and that “the world of microbes will proceed to carry out their functions and come to new steady states, whereby their metabolism maintains a habitable planet”.

But he is concerned about our genetic tinkering with microbes when “we don’t understand what we are doing”. Falkowski argues that the problem lies with the approach of synthetic biologists, who do not concern themselves with Earth systems but with specific tasks within them – making a microbe that can better fix nitrogen, for example, or one that can carry out the task of photosynthesis more efficiently.

He acknowledges that for the most part these are “noble attempts to develop a future that is sustainable for humans” but he also fears that we are courting a potential disaster of unintended consequences. “Microbes have made this planet habitable for themselves and, ultimately, us. We are only passengers on the journey; however, we are tinkering with the organisms at the controls.”

— BILL CONDIE



SCIENCE FICTION

Lullaby

by BERNARD BECKETT

Text Publishing (2015)

NEW ZEALAND AUTHOR Bernard Beckett’s biggest strength isn’t that he is able to convey high-minded sci-fi concepts to his usual audience of young adult readers – it is the power of the concepts themselves. His 2005 novel *Genesis* raises a grand philosophical theme before a final-sentence twist that shines an extraordinary new light on what has come before.

For a while *Lullaby* might make you think he’s moved away from any sci-fi elements (Beckett doesn’t consider his work as primarily science-fiction), but around page 60 he reveals we are in a world of astonishing technological possibility.

A teenage boy named Rene sits with his identical twin brother Theo in hospital, the latter in a coma which is likely to be permanent. Rene is taken away and interviewed by psychologist Maggie to determine his emotional suitability for a procedure that’s hinted at but not explained.

Through talking to Maggie and reminiscing inside his own head, Rene imparts how he and Theo used to play a game on friends and peers – sometimes for days at a time – where they’d dress as each other and take the role of the other brother.

Until he sits down with Maggie to relate it, Rene does not know he and his brother were testing the fluidity of individual identity – a motif that forms the theme of the book.

The jaw-dropping moment comes when a doctor talks about the futuristic procedure under consideration. Because Theo’s neuro-connected mind rather than his physical brain is damaged, a scan of Rene’s brain can be taken and implanted in his brother’s head.

Theo will awaken with a virtual copy of Rene’s memories and sense of self while living inside his own body – prompting the question of what identity means. It’s exciting to see a recent scientific concept such as the connectome (a map of neural connections in the brain) used to drive dramatic tension and ask big questions.

Most of the book concerns Rene’s melancholy and false bravado as he tries not to let on how lost and scared he is to the psychologist. The science provides a thrilling backdrop.

— DREW TURNERY

Uranium – desired and feared



DOCUMENTRY

Uranium:
Twisting the dragon's tail

Genepool Productions (2015)
Three-part series will be broadcast on
PBS from 28 July; ZDF/Arte from 31 July
and SBS from 9 August

THIS IS A FASCINATING TALE about a subject you probably don't know half as much about as you think you do – or as much as you probably should.

The first part takes us from the genesis of uranium – “the most desirable and the most hated rock on Earth” – as it is forged in the heart of a supernova, to its nuisance value to early Czech silver miners, to the discovery of its power and how it became the basis of the most destructive weapon the world has seen.

The second episode looks at the atomic age of the postwar years, where the chic excitement of a world in which everything

had changed partied in the shadow of mutually assured destruction.

The third part of the series assesses our ability to balance the dream of limitless clean power with the nightmare of a silent poisoned Earth.

The series is brilliantly written and directed by Wain Fimeri and presented with panache by Derek Muller, founder of YouTube channel Veritasium, undoubtedly one of the most talented science communicators of our time.

It is produced by Emmy Award-winning Australian science television specialists Genepool Productions, for SBS Australia, PBS America, and ZDF/Arte (Germany/France).

This is one not to be missed.

— BILL CONDIE

IMAGE
Josephine Wright / Genepool Productions
Pty Ltd

TOP 5

Bestsellers

1

The Wright brothers
by DAVID McCULLOUGH

Simon & Schuster (2015)
RRP \$30.00

2

Being mortal: Illness, medicine
and what matters in the end
by ATUL GAWANDE

Profile Books (2014)
RRP \$32.99

3

On the move: A life
by OLIVER SACKS

Macmillan (2015)
RRP \$34.99

4

Elon Musk: Tesla, SpaceX,
and the quest for a
fantastic future
by ASHLEE VANCE

Ecco / HarperCollins (2015)
RRP \$28.99

5

David and Goliath: Underdogs, misfits,
and the art of battling giants
by MALCOLM GLADWELL

Penguin (2014)
RRP \$22.99

— FROM THE NEW YORK TIMES
SCIENCE BESTSELLER LIST

JASON ENGLAND is a magician based in Las Vegas and a renowned authority on casino gambling and card handling.

Smoke & Mirrors

Executive desk toys explained

Newton's Cradle and the MOVA globe both work on old scientific principles.

I'VE BEEN COLLECTING unusual toys, gadgets and puzzles for almost two decades. Due to my interest in science, most of them incorporate some sort of scientific principle. Let's look at two of my favourites.

Most people are familiar with Newton's Cradle: four or five steel balls suspended by wires from a frame. If one of the balls at either end is raised and released it will swing back to its original position and strike the remaining balls in the row. This causes the first ball to stop, while the ball at the opposite end of the row swings up. This action repeats itself until the apparatus winds down and stops over the course of a minute or two.

The action is hypnotic and elegant. The cradle rocks with a predictable rhythm that is mesmerising to behold.

The executive toy illustrates the principles of conservation of energy and conservation of momentum. Imagine a Newton's Cradle with only two balls. Raise and release one of the balls. The momentum in the first ball is "lost" when it strikes the second ball. The first ball comes to a near-immediate stop. However, the laws of physics don't allow that momentum to vanish — it has to go somewhere. So the second ball is knocked into the air and will travel to almost exactly the same height from which the first ball was released. That's conservation of momentum in action. The reason the

second ball doesn't travel to exactly the same height as the first ball is because some of the energy escapes as friction due to air resistance as well as a tiny amount of heat that is generated on impact. The total energy in the system, as well as the momentum, is conserved and accounted for.

Newton's Cradle uses principles that have been known for centuries. My second favourite scientific toy is a newcomer. While still based on ancient knowledge, it incorporates technology that didn't exist when Newton's Cradles first appeared in the late 1960s.

The MOVA globe is a small plastic model of the Earth approximately 40 centimetres in circumference. A close look reveals there are two globes — an outer sphere of clear plastic and an inner sphere with the printed map of the Earth on it. A thin layer of clear liquid separates the two spheres. If the MOVA globe is placed on a level surface and allowed to sit quietly for a few seconds, the inner globe will begin to rotate slowly. What causes the spinning is the "mystery" of the MOVA globe.

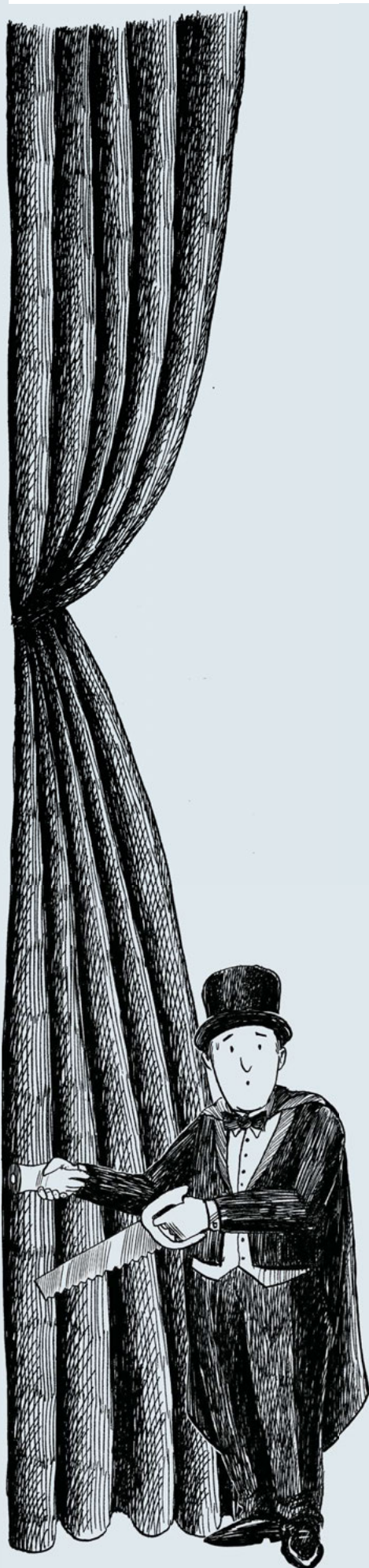
See if you can work it out. I'll give you some hints:

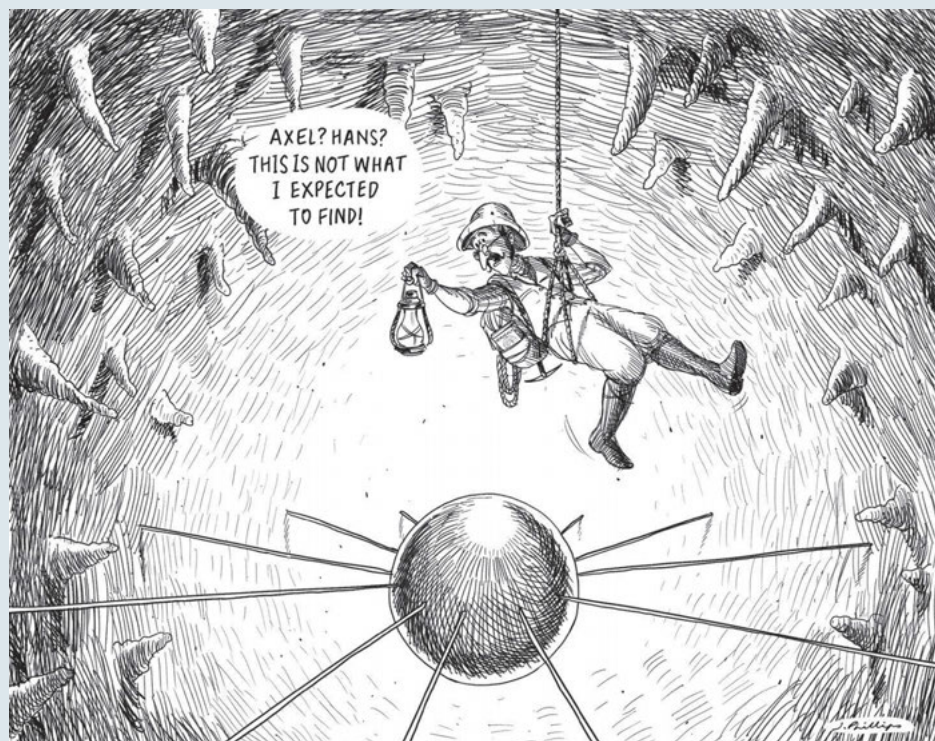
1 — A "mechanism" is hidden within the toy — the spinning is not the result of vibrations or residual energy left over from handling the globe.

2 — The mechanism operates smoothly and will run continuously for years as long as it has a decent light source — sunlight is best, but an incandescent light bulb will work.

3 — Other than the spinning printed globe, it has no moving parts.

When I first saw a MOVA globe almost 10 years ago, I had no idea what made it spin. Puzzle collector and expert Jerry Slocum explained the secret to me. As you may have surmised from hint number two, the globe is solar powered. Light enters through the printed material of the inner globe and powers some hidden circuitry. Also concealed within the inner





A MOVA globe's interior contains an intriguing secret. ILLUSTRATIONS: JEFFREY PHILLIPS

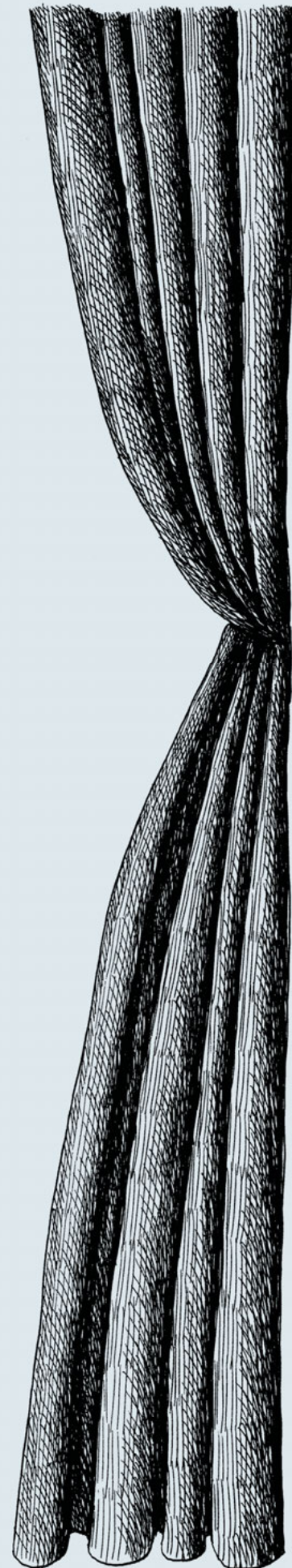
globe are two or more bars that cross at the centre and are attached to the inner surface of the printed sphere, like spokes of a wagon wheel attached at points around the globe's equator.

When a set of these bars or "spokes" is energised, they generate a magnetic field. This magnetic field then tries to align with the Earth's magnetic field. In essence, the toy has become a compass. It spins in an effort to "point" north. After a few seconds, the inner circuitry shuts off the first set of energised spokes and energises a different pair. This new set of magnetised spokes then tries to point north and the globe spins a bit more. This constant switching from one

set of spokes to another is what keeps the internal "compass" spinning.

A careful reading of the MOVA globe patent reveals the inner globe is floating in two different liquids. Both are clear but they have different densities – the heavier fluid sinks to the bottom and the lighter fluid rises. The inner globe is dense enough to stay in between these two fluids and doesn't sink to the bottom of the outer clear plastic sphere or float to the top – either might cause friction that would interfere with the spinning globe.

Newton's Cradle may win the prize for simplicity, but the MOVA globe is the champ when it comes to ingenious engineering. ©



WHY IS IT SO?

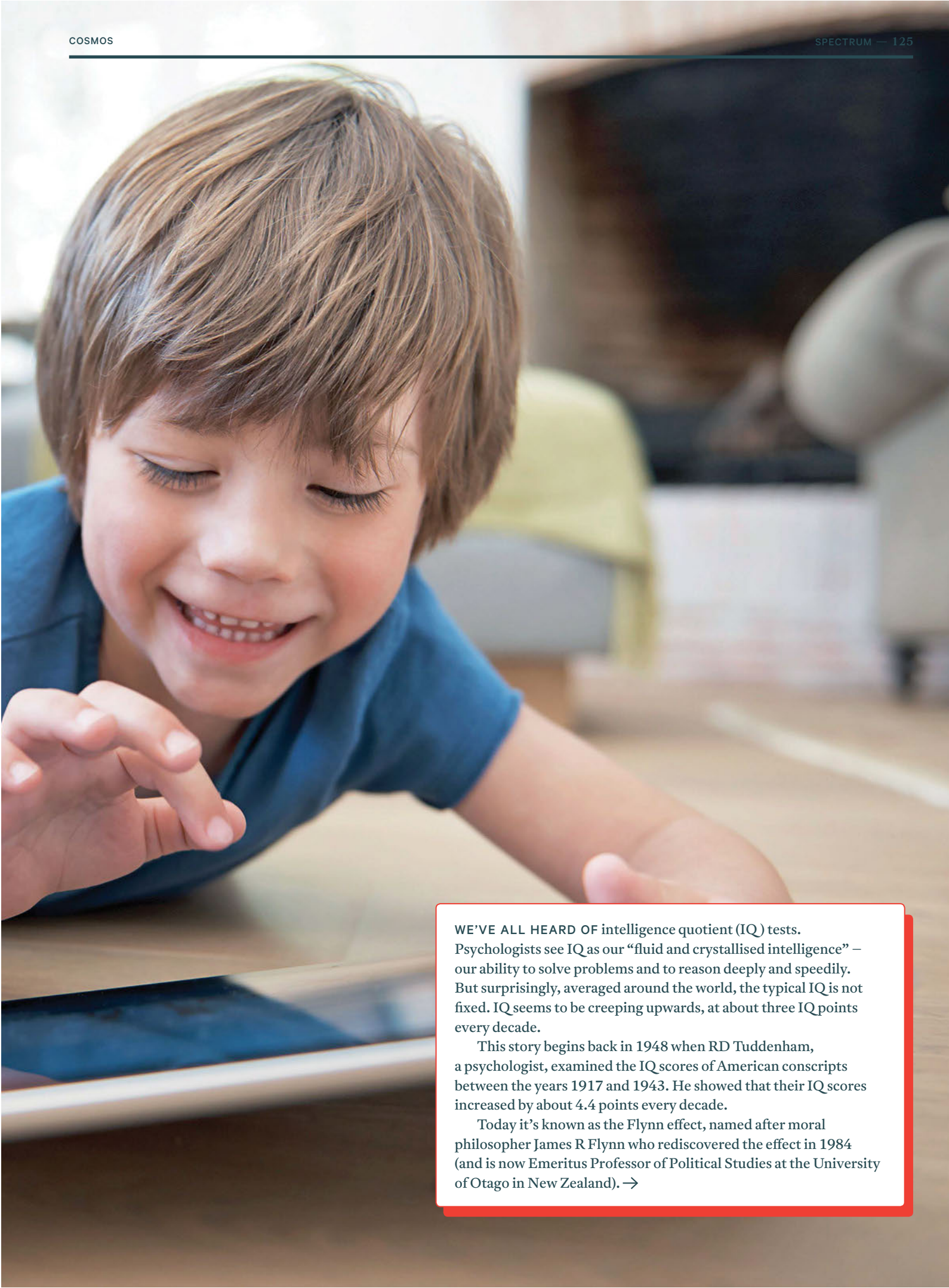
WHY ARE CHILDREN SMARTER THAN THEIR PARENTS?

IQ test scores have been creeping upwards for a century, writes
KARL KRUSZELNICKI.



01

IQ tests indicate children are adapting well to a contemporary environment.



WE'VE ALL HEARD OF intelligence quotient (IQ) tests. Psychologists see IQ as our “fluid and crystallised intelligence” – our ability to solve problems and to reason deeply and speedily. But surprisingly, averaged around the world, the typical IQ is not fixed. IQ seems to be creeping upwards, at about three IQ points every decade.

This story begins back in 1948 when RD Tuddenham, a psychologist, examined the IQ scores of American conscripts between the years 1917 and 1943. He showed that their IQ scores increased by about 4.4 points every decade.

Today it's known as the Flynn effect, named after moral philosopher James R Flynn who rediscovered the effect in 1984 (and is now Emeritus Professor of Political Studies at the University of Otago in New Zealand). →

IQ TEST EXAMPLES

WISC

Q1. How are lizards and crocodiles similar?

Q2. What is this?



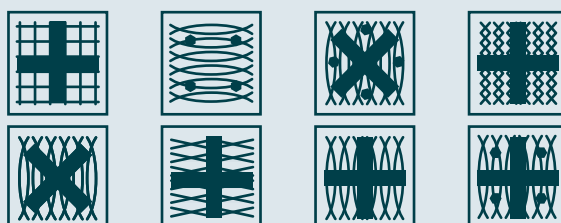
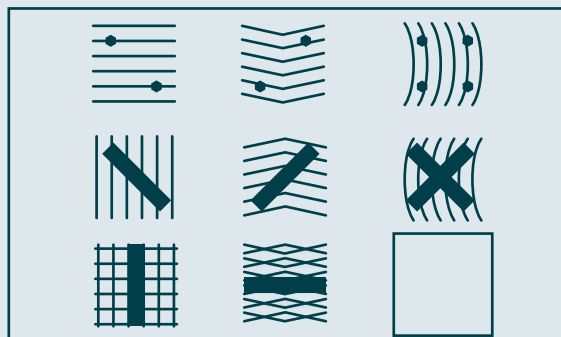
Q3. Robyn is three years younger than Viviane and five years older than Belinda. If Belinda is 12, how old is Viviane?

Raven test

Q1. Match the missing piece



Q2. What goes next?



Answers will be published online
at cosmosmagazine.com/answers

→ IQ tests are limited in scope. You can see this by looking at a typical IQ test, the Wechsler Intelligence Scale for Children (or WISC). The WISC tries to measure 10 different “aspects” of this strange beast we call IQ including information (“On what continent is India?”), arithmetic (“If three toys cost four dollars, how much do seven toys cost?”), vocabulary (the words we use in everyday life), comprehension (“Why are houses in a street given numbers?”), picture completion (in which you find the missing part in a picture) and similarities (“How are dogs and rabbits related?”).

Another widely used test is Raven’s Progressive Matrices, suitable for children aged five and up. It uses patterns in an attempt to measure on-the-spot problem solving ability. There are 60 multiple-choice questions which get progressively more difficult. In each question you are asked to point out the missing element to complete a given pattern. Ability to do the test seems to be largely independent of the culture you live in, or your education.

Getting back to the WISC – over the past 70 years or so it’s been recalibrated three times to make sure that the average measured IQ of children was always 100. The original WISC was released in 1947. It was recalibrated (or “renormed”) upward in the early 1970s and renamed the WISC-R, and renormed up again in the late 1980s and called the WISC-III. Most recently it was renormed up in the early 2000s, and renamed the WISC-IV. Each version was harder than the one before it. (And then the WISC-V, the WISC-VI, etc.)

And here’s the essence of the Flynn effect. If you give a child of today one of the WISC IQ tests of the past, on average, that child will score more than 100.

But if you look at each of the 10 components that make up the WISC, you’ll see differences in their scores over time. On one hand there has been virtually no increase in “arithmetic” scores over the decades. But over the same time, there has been a huge measured increase in “similarities” scores. We’re not sure why.

A similar increase has been seen in the non-mathematical and non-verbal Raven’s Progressive Matrices. Indeed, the Raven’s Progressive Matrices shows some of the highest gains in measured IQ.

So what’s causing the Flynn effect? We don’t know for sure, but many explanations are offered.

Compared to a century ago, our brains have

to work within an environment that is more abstract. Today’s world is loaded with synthetic visual imagery – televisions, computers and video games. So results on an abstract category such as “similarities” could be improved more than “arithmetic”.

Another set of changes over time involves the home and physical health. Children now get better nutrition during their formative years when the brain is growing. Smaller families mean that parents can theoretically spend more time with and money on the fewer kids. A higher standard of living can mean fewer infections, so children’s potential growth is not hindered. A 2010 study showed a strong link between early childhood vaccinations and the average IQ of a nation.

The Flynn effect also seems to kick in strongly when countries achieve a certain level of health, education and welfare.

Another way to interpret this is to see your IQ not as something set in stone and unchangeable but, rather, more like a muscle that can alter itself and adapt to a changing environment. So IQ is a measure of how well we can deal with the society we inhabit. In other words, perhaps it’s a measure of how “modern” we are.

But we still don’t understand the full ramifications of the Flynn effect. According to Flynn, if these gains in IQ are actual and real, “Why aren’t we undergoing a renaissance unparalleled in human history? Why aren’t we duplicating the golden days of Athens or the Italian Renaissance?” Perhaps we are, but we can’t see it because we are in the middle of it.

So OK, it’s not as easy as ABC to test IQ... And maybe teenagers were right all along, and they really do know more than their parents. ☺

KARL KRUSZELNICKI is an author and science commentator on Australian radio and television.

CREDIT: Edited extract from *House of Karls*, Macmillan 2014

IMAGES

01 shapecharge / Getty Images

02 Cosmos Magazine / Getty Images

ILLUSTRATIONS

Jeffrey Phillips

EVENT



Cosmonauts: Birth of the Space Age

Opens 18 September 2015
Science Museum, London UK

DID YOU KNOW that Russia was the first country in the world to launch an artificial satellite, Sputnik, back in 1957? And four years later, they also launched the first human – Yuri Gagarin – into space? Russian space travel played a significant role in shaping the nation in the early 20th century. In this special exhibition, you

can explore all there is to know about Russian space travel and how they turned space travel from aspiration to actuality. A vast collection of Russian spacecraft and artefacts will be on display, including the Vostok-6, the capsule flown by the first woman in space, Valentina Tereshkova. There will also be testimonies and memorabilia from the Russian pioneers who helped launch the space age. The exhibition will be open until 10:00 PM every Friday.

→ bit.ly/SMLcosmonauts

IMAGE

Yuri Gagarin before the first space flight, April 12 1961, c. RIA Novosti

WHERE IN THE COSMOS?



Tania de Jong and Peter Hunt are reading *Cosmos* in front of the chateaux that was the abode of the Marquis De Sade. It crowns the village of Lacoste in Vaucluse, France.

Pierre Cardin now owns the castle and holds a summer music festival in the nearby quarry.

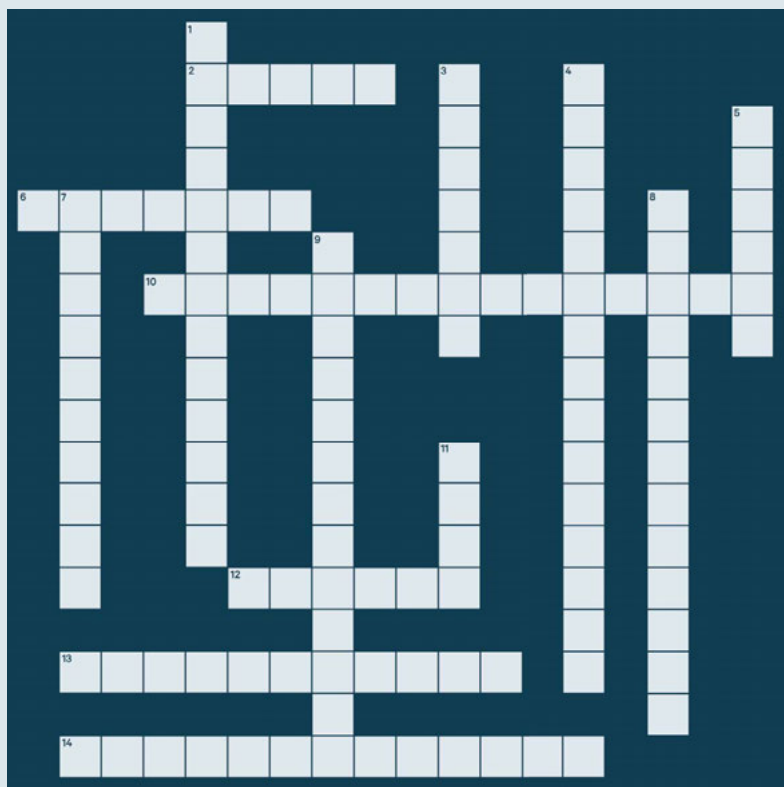
MIND GAMES

Quiz

- Q1. What is the “quantum bit” in a silicon quantum computer?
- Q2. What will search for dark matter?
- Q3. Calculations done by Megan Bruck Syal and her colleagues suggest Mercury’s surface could be up to 6% of this element.
- Q4. What do foreign antigens do?
- Q5. American astronomers Arno Penzias and Robert Wilson accidentally discovered this in 1960.
- Q6. Name the enforced quiet zone for radio telescopes in Virginia?
- Q7. How long can the most accurate clock ever made tick for without losing time?
- Q8. Name four distant worlds also found in the Kuiper Belt alongside Pluto.
- Q9. What are “extreme trans-Neptunian objects”?
- Q10. At what frequency does the peacock tail emit its “secret signal”?
- Q11. Name other animals that can communicate by making low-frequency rumblings in their larynx.
- Q12. What can map a chemical’s distribution through a sample?

Answers will be published in issue 65

Cosmos crossword



ACROSS

2. Blood type can be given to almost anyone (1,4)
6. Where the Apex chert microfossils originated
10. Less than 2mm in size, they cover Mercury's surface
12. Pluto's largest moon
13. Term used to describe exoplanets that are 2-15 times larger than our own (5,6)
14. Material in 'cell walls' of disputed microfossils (8,5)

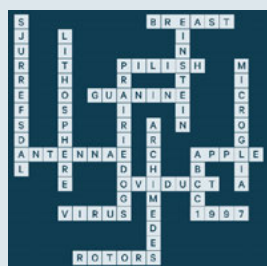
DOWN

1. Some scientists believe the oldest known fossils are just what? (8,5)
3. Ye aims to make clocks accurate enough to detect changes in?
4. How Morello controls each quantum bit (10,5)
5. Enzyme in *Streptococcus pneumoniae* that chops up sugar chains while the bacteria digest food
7. Noise generated by rustling peacock feathers
8. Clocks activated by visible light are also known as? (7,6)
9. The radio telescope 20 kilometres east of Hobart (5,8)
11. A satellite similar in size and composition to Mercury

Answers will be published in issue 65

SOLUTIONS: COSMOS 63

CROSSWORD



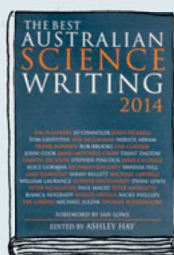
QUIZ

1. a. Cancer drug 5FU
b. A chemical dye
2. Beta amyloid, found outside of brain cells, and tau, inside them
3. The blood-brain barrier is the near-impenetrable layer of cells that line blood vessels in the brain
4. A quasar is one of the brightest objects in the Universe and is generated by a feeding black hole. As matter is sucked in, it radiates intensely bright light
5. In an intergalactic trick of the light, a supernova has appeared at four places at once, creating an 'Einstein cross'.
6. Around 400,000 kilometres per hour
7. Four billion years' time
8. Lithosphere
9. 10 kilometres

WHERE IN THE COSMOS?

Send a photo of yourself reading a copy of *Cosmos Magazine* in an interesting place to competitions@cosmosmagazine.com.

Tell us your name, the names of others in your picture, your address, what you're doing and why you're there. Each published entrant will receive *The Best Australian Science Writing 2014*, published by New South Books.



WINNERS

The transistor scaling rule – Dennard's Rule – was named after IBM engineer Robert Dennard.

Congratulations to our three winners for answering correctly: Stephen Thyer, Lesmurdie, WA; Samantha Waugh, Coombabah, Queensland and Bob McCrossin, Cooroy, Queensland! They will each receive a *Cosmos* prize pack.

PORTRAIT

Vanessa Kellermann, evolutionary biologist

NEVER UNDERESTIMATE the impact of an inspirational science teacher — just ask Vanessa Kellermann, who was lucky enough to be taught by two of them at her Melbourne high school, encouraging her to pursue a science degree. Now, after a two-year stint working in Denmark, the evolutionary biologist is back in Melbourne at Monash University to investigate how climate change affects insects.

Instead of looking at the long-term genetic changes a species might use to adapt to a warming climate, Kellermann studies “phenotypic plasticity”, or rapid change within an animal’s lifetime, to see how different species deal with day-to-day temperature spikes and dips.

“Leave a fly in a warm water bath and the next day it’ll be able to stand hotter temperatures,” she says, adding that epigenetics — factors that turn genes on or off — is likely to be responsible for this.

But not all species are equally flexible. Kellermann is testing the theory that tropical insects can’t cope with temperature swings as much as their temperate counterparts — they prefer to move en masse to a more hospitable area. By finding out what affects species distribution in a warming world, her work will help reveal how crop pollinators and disease carrying pests will act.

— BELINDA SMITH

IMAGE
Peter Tarasiuk



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Kylie Rivers, Consultant at Thinc,
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